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THE GEOLOGY OF THE PRODUCING PART OF THE TONOPAH MINING DISTRICT

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CONTENTS.

Introduction 681
Maps and Sections 682
Lower Rhyolite 687
Rhyolite Dike 690
Calcite Andesite 691
Upper Rhyolite 692
Earlier Andesite 699
Productive Veins 701
Later Andesite and Other Later Formations 703
Faulting and Folding 709
Summary of Geological History 711

INTRODUCTION.

It is the purpose of this paper to present an interpretation of the structure of the Tonopah mining district, differing materially from that heretofore entertained. The "Geology of the Tonopah Mining District," by Mr. J. E. Spurr,[1] formed as complete a description of the district as could be compiled at that time; but in 1905 sufficient mine work had not been done to afford the basis for a confident determination of the relations between the earlier andesite and the underlying rocks. At the present time it is thought that mine workings have been sufficiently extended to

[1] U. S. G. S., Professional Paper, 42, 1905.

supply this deficiency; and to justify the construction of the accompanying geologic sections and the formulation of a hypothesis based upon them.[1]

The solution of the geological problem here offered is that the district is built up of a series of successive lava flows and tuffs. This differs from Spurr's hypothesis, which proposed that the earlier andesite was the oldest of the rocks exposed and that it was intruded by the rocks here designated as the upper and lower rhyolites. The present departure from the theory of the intrusive nature of these rocks is suggested by the comparative uniformity of depth and area within which the upper rhyolite has been found, and from this it is easy to take the next step of regarding all the rocks as surface-formed sheets. It has been found that this conception of them is well supported by the evidence at hand.

MAPS AND SECTIONS.

The accompanying map, Fig. 80, has been copied, with some alterations, from Spurr's report. It illustrates the surface distribution of the rocks shown in the sections. The area crossed by the sections lies almost wholly within the productive part of the district, but does not cover all the producing mines, especially those in the western part of the camp. The writer has a fair degree of familiarity with the mines not represented, and has seen nothing in them that is inconsistent with the scheme here outlined.[2] Development in the outlying, non-producing mines has seldom penetrated below the horizon of the earlier and later andesites, and consequently gives little positive information as to the position and character of the underlying rocks. The

[1] The writer wishes to acknowledge his indebtedness to Professor A. C. Lawson for numerous helpful suggestions regarding this work. Thanks are also due to Mr. E. D. North for furnishing the sections of the Montana Tonopah Mine, to Mr. E. S. Larsen for microscopic work on the lower rhyolite, and to Professor G. J. Young for chemical analyses.

[2] The information in this paper concerning the workings from the Desert Queen shaft was obtained while the writer was connected with that mine. It does not represent the development of the past two years, excepting the drift reaching out towards the Belmont shaft.

best information regarding the rocks in these mines is to be found in Mr. Spurr's paper. The writer has had little opportunity for inspecting them, owing to the cessation of work in them before

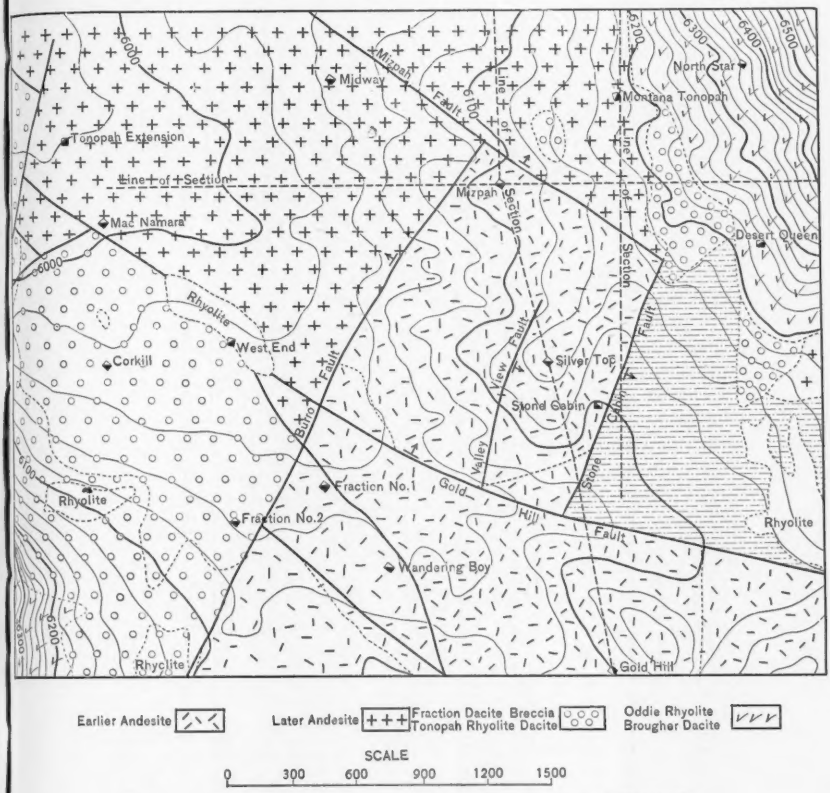

FIG. 80. Geologic surface map of the producing area of Tonopah.

or shortly after his arrival in the district in 1906, and therefore no attempt has been made, in the sections, to indicate the geology beyond the limits of present accessible workings; and the discussion which follows will be confined mainly to these limits.

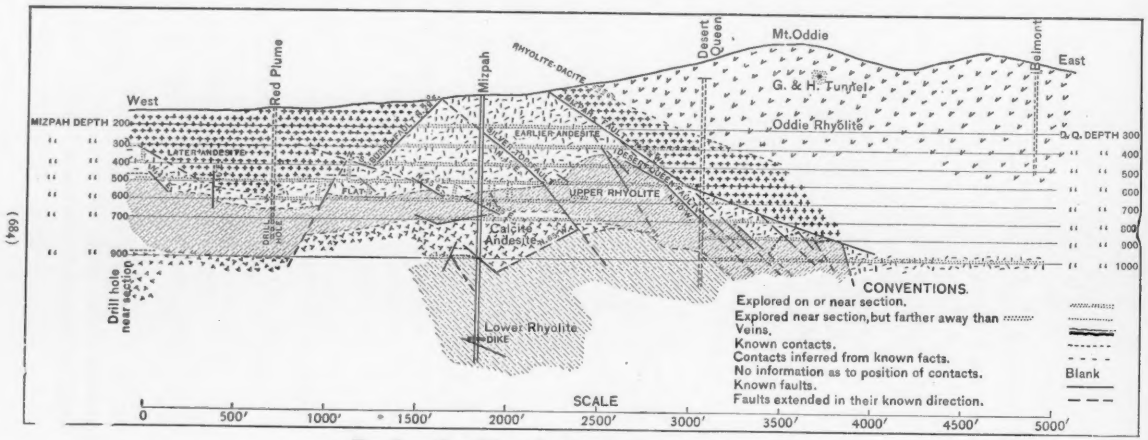

FIG. 81. East-West Section through Mizpah Shaft.

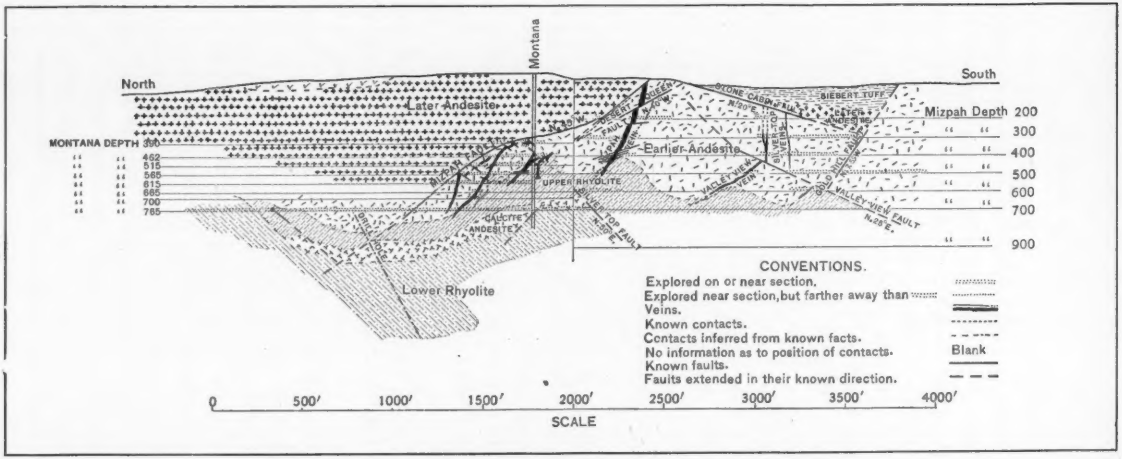

FIG. 82. North-South Section through the Montana Tonopah Shaft.

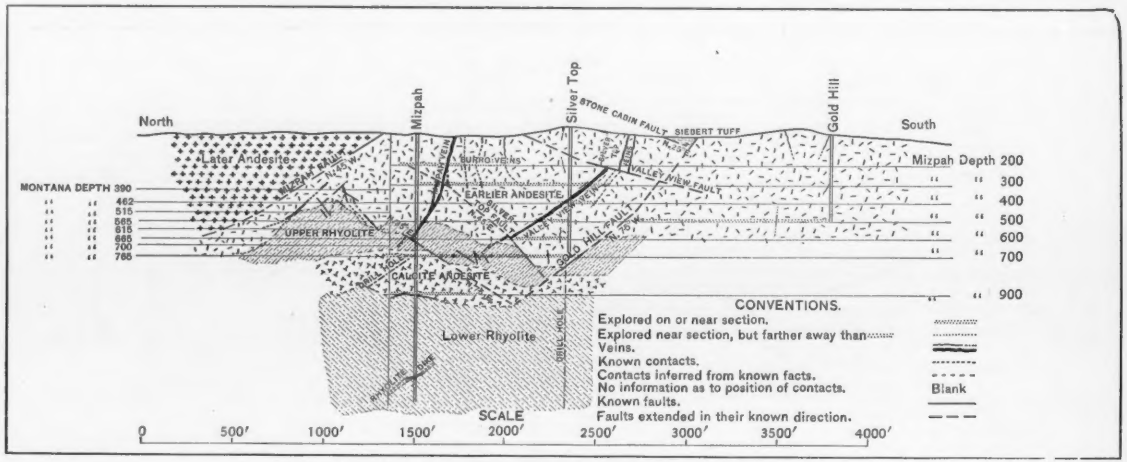

FIG. 83. Section on Line of Mizpah and Silver Top Shafts.

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LOWER RHYOLITE.

The lower rhyolite is the oldest of these rocks. It has been found wherever mine workings have penetrated below the calcite andesite. This has been accomplished in the following places: in the Mizpah shaft, in the Montana shaft, in a cross-cut east and drill-hole north from the Mizpah shaft on the 700 foot level, in a drill-hole from the Silver Top shaft, in a drill-hole from the Montana workings, and probably in the Desert Queen shaft. All these exposures are shown in the accompanying sections.

In the Mizpah shaft the rock presents a fairly uniform appearance. It is a light-colored, greenish-gray, hard, compact rock. It contains numerous small grains of quartz and feldspar, and occasional small angular fragments of foreign rocks, such as granite, andesite, carbonaceous shale, rhyolite. At a depth of 1,365 feet a dike three feet in thickness was encountered, which will be described elsewhere.

In the Silver Top drill-hole, the rock is not as uniform in character as in the Mizpah shaft. After passing through 86 feet of normal rhyolite, the hole encounters a 36-foot body of white altered rock, containing sparsely scattered crystals of white feldspar, and for twenty feet below this stratum the rock consists of interbedded layers of indurated tuff and breccia. The contacts between tuff and breccia are distinct and are plane and parallel and usually dip at an angle of 60°. A photograph of this part of the core is shown in Fig. 84.

Where exposed in the cross-cut on the Mizpah 700-foot level, 500 feet east of the shaft (shown in Fig. 81, at a depth of 750 feet by projection), the lower rhyolite consists of perfectly stratified tuff and breccia, tilted to an angle of about 45°. The separate layers are composed of well assorted material, which varies in different layers from fine ash to coarse breccia, and which are from one eighth of an inch to eight inches thick. The material composing the strata has been indurated to a rock of soft or medium hard consistency. It has a clay odor when dampened. The contacts between the layers are plane and parallel, and form distinct parting planes when the rock is broken. There has been

no internal movement in the rock or between the strata since its deposition, although it has been tilted and faulted in large blocks. A photograph of a specimen of this rock, marked 407, is shown in Fig. 84.

In the drill-hole from the Montana workings and in the one from the Mizpah 700-foot level, the lower rhyolite possesses the same general characteristics as in the places just described, but in places partakes more of the nature of a flow than of a consoli-

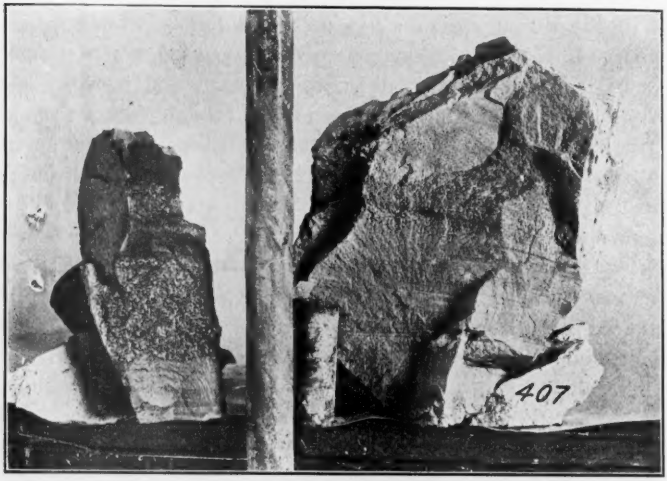

FIG. 84. Indurated stratified tuff from the lower rhyolite. Specimen No. 407 mentioned in the text. Core from Silver Top drill-hole. Size of large specimen 9 x 7 inches.

dated tuff. It has not been examined in thin section. As shown in the Montana drill-hole, there are layers within the rhyolite of what are probably latite or andesite, but which are much altered and have not been analyzed or examined microscopically. The writer has not been to the bottom of the Montana shaft, but has good authority for the statement that the rock there is a rhyolite similar to that just described.

The rock at the bottom of the Desert Queen shaft is a rhyolite,

and although the writer has not seen it for two years, he would classify it from memory with the rock at the bottom of the Mizpah shaft. This has been the opinion of all who have seen both rocks. If this is correct, it means that the calcite andesite is not represented at this place, and that it wedges out between the Mizpah and Desert Queen shafts as shown in Fig. 81, and this explanation seems probable. The present hesitation to be positive of this is due to the recognition of the possibility that the rhyolite, at the bottom of the Desert Queen shaft, is a lower phase of the upper rhyolite.

Specimens and thin sections of the lower rhyolite from the Mizpah shaft and Silver Top drill-hole were sent to Mr. E. S. Larsen, of the Carnegie Institute, for examination and were reported on by him as follows:

> The specimens, with the possible exception of No. 90 (the white altered rock found in the Silver Top drill-hole) are all tuffs. Some of them might be flow-breccias but I do not think it at all likely. Many of the specimens are made up of angular fragments of different rhyolitic rocks which are imbedded in a fine matrix, which shows no evidence of being a flow, but has broken fragments of quartz and feldspar in a fine dust-like base. Alteration is usually extensive. Some of the specimens show fragments of a quartzite.
>
> The other specimens have no fragments of rock, but are similar to the matrix of those above. They consist of a varying amount of fragments of quartz and feldspar in a fine paste which is typically tuffaceous. Specimens No. 407 (four sections and specimens from the strata on the 700-feet level of the Mizpah) are well-bedded tuffs and are similar to the other rocks though made up of a little finer material.
>
> The rocks are made up of quartz, orthoclase, plagioclase and altered biotite, and are rhyolites or quartz latites. I feel no hesitation in calling them tuffs. The abundant fragments of rock of different kinds, the fragmental character of the quartz and feldspar, and the character of the enclosing paste, all point in that direction as well as the fact that No. 407 is surely a tuff. I have not described the specimens separately as one description practically fits them all.

ANALYSIS OF THE LOWER RHYOLITE.[1]

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
75.17	15.83	0.90	0.46	0.39	2.08	3.18	0.61	0.17	2.16	100.95

From the foregoing description of the rock, together with its silica content of 75.17 per cent., the lower rhyolite may be regarded as a complex of rhyolitic tuffs, breccias and flows, with possible interbedding of latite. It cannot be intrusive. As indicated by the apparent unconformity between the overlying andesite and the tuff beds, the rock was tilted and suffered erosion before the outflow of the calcite andesite.

In sinking the Mizpah shaft through this rock a permanent flow of water was encountered at a depth of 1,230 feet. The water has a temperature of 94° F. and is slightly alkaline. The rate of flow is 60 gallons per minute.

RHYOLITE DIKE.

The dike at the 1,365-foot point in the Mizpah shaft is about three feet thick. It strikes east-west and dips about 45° north. It is rhyolite with exceptionally well developed porphyritic structure. It contains numerous quartz phenocrysts and well-developed crystals of orthoclase and plagioclase, with a lesser amount of altered ferro-magnesian mineral. The accessory minerals are apatite and magnetite. The quartz phenocrysts have been subjected to much corrosion by the groundmass, and are roughly of spherical form. The embayments have taken the shape of irregular tubes through the quartz, and are so numerous that they give the specimen the appearance of a section through the coarser variety of sponge. The material in the embayments or tubes has been replaced in some phenocrysts almost entirely by quartz and to a less extent by calcite. In some tubes the quartz has formed in interlocking grains of varying orientation; in others it has grown in crystallographic continuity with the quartz of the phenocrysts. The quartz in the tubes is readily distinguished from the original quartz of the phenocryst by the numerous dusty

[1] The rock analyses in this paper were made by Professor G. J. Young of the University of Nevada.

inclusions in the former. Some of the tubes contain sericite and various other alteration products of the glass, instead of quartz. The original quartz is irregularly cracked, and contains swarms of fluid inclusions. Many of the cavities are not completely filled with the fluid, but contain minute bubbles, some of which are moving rapidly within the liquid. The quartz encloses accessory apatite and magnetite. Some of the feldspars look pink and fresh in the hand specimen, but many of them are much altered. Some of them are altered to a fine grained mica. Of those that are not completely altered, some prove to be orthoclase and some plagioclase, and intergrowths of the two are common. The orthoclase crystals are the largest and freshest, and some of them attain a length of three fourths of an inch. The plagioclase shows small extinction angles of 5°. The ferro-magnesian mineral has altered to green chlorite which shows faint pleochroism. Judging from the outlines of some of the individuals, they consisted of biotite and hornblende. The groundmass is devitrified and consists mostly of finely mottled patches of quartz sometimes interlocking. It contains some veinlets of sericite and patches of calcite. The border facies of the rock is of finer grain than the middle, and the contacts are typically those of an intrusive.

CALCITE ANDESITE.

The calcite andesite, the name by which this rock is commonly known, is a shortened form of Spurr's term, "the calcite phase of the earlier andesite." The rock was originally a hornblende andesite of structure and composition similar to the earlier andesites. It owes its color chiefly to chlorite, which is present as an alteration product of the original ferro-magnesian minerals. In thin section, calcite, chlorite, quartz, sericite, pyrite and probably kaolin, are seen to be the most prominent among the alteration products composing the rock; while in fresher portions striated feldspars, only partly decomposed, may be found. By the Michael Levy process their extinction angles prove them to be andesine-oligoclase. The rock seems to have been originally a

ANALYSIS OF THE CALCITE ANDESITE.

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
56.40	20.12	5.87	3.55	1.99	4.87	2.56	2.59	0.09	2.41	100.45

continuous sheet of varying thickness, throughout the greater part of the district. It is not found in the Desert Queen shaft, but west of there it has been found under the upper rhyolite wherever mine workings have extended below that rock. In the Mizpah shaft it occurs at a depth of 700 feet, and allowing for faulting and folding, it lies at a fairly uniform depth wherever found. Its thickness is known to be over 280 feet in the western part of the camp.

It was probably deposited on an uneven surface of erosion; and if its deposition were also followed by erosion, this would account for its varying thickness, and its entire absence in the Desert Queen shaft.

UPPER RHYOLITE.

The upper rhyolite, popularly known as the "dacite intrusion," is the body of rock that overlies the calcite andesite. It is mostly of a uniform type, but the sheet is a complex of several flows. The normal facies, that met with most commonly, is a dense rock of fine texture with a pale greenish-gray color. Porphyritic structure is not developed. The rock has an argillaceous odor when wet, which indicates the presence of much kaolinic substance. The joint surfaces are usually talcy.

The rock is much altered. Under the microscope, by ordinary light, the section looks murky with alteration products. Between crossed nicols the mass of the rock is seen to be composed principally of colorless mica, kaolinic substance and secondary quartz. The mica is in minute flakes showing high interference colors and is probably sericite. It is evenly distributed and covers about half the area of the section, but owing to its flaky nature it is doubtless of less quantitative importance than this observation would indicate. In parts of the section the mica is gathered into wavy non-persistent lines, having an imperfect parallelism and giving the section between crossed nicols a silky sheen, a

feature which is characteristic of all the sections of this rock examined. Primary quartz is represented by small angular fragmental particles, of which there is seldom more than one grain in a section. Secondary quartz, as an alteration product, forms the bulk of the rock. It is usually evenly distributed through the groundmass, where it is recognized in microscopic areas by its transparency and its low birefringence. It also forms veins varying from minute veinlets to veins of considerable size. Pyrite, with pseudomorphs of iron oxide, or occasionally of yellow epidote after pyrite, is found in it. Originally the rock was probably a quite glassy lava of the nature of obsidian, which has been affected by devitrification.

ANALYSIS OF UPPER RHYOLITE.

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
73.20	14.59	1.92	0.47	1.24	0.12	4.32	0.32		2.98	99.16

From its mineralogical characteristics and its chemical analysis showing 73.20 per cent. silica, the rock is here classed as rhyolite. The specimen analyzed was taken from as fresh a portion of the rock as could be found, but was altered. Stratigraphically it is classed as a flow sheet.

There are several exposures of rhyolite at this horizon which are continuous with the rhyolite just described, but which differ from it in appearance. In the MacNamara mine the upper parts of the rhyolite have the usual characteristics, but the lower part is crowded with fragments of a dense white rhyolite. The paste in which the fragments are imbedded looks more siliceous than the normal rhyolite, but otherwise resembles it. This phase seems to be part of the main flow. It is thought that the fragments were formed by the crushing of a part of the rock soon after hardening, and that they were picked up by a part of the magma that was still molten. This phenomenon was observed by Spurr and was termed "autobrecciation" by him. In the normal facies occasional included fragments are found, altered to a characterless chalky substance.

In the northern part of the Tonopah Mining Company's property there are two exposures of an altered rhyolite showing

crowded, ropy flow lines. The rock is of a light gray color. The flow laminations are wavy and are as frequent as fifty to the inch. They are composed of light gray impure quartz, alternating with bands of white decomposition products. In thin section the quartz forming the bands is seen to be composed of interlocking grains. This indicates that it is of secondary origin, and is an alteration product which has preserved the structure of the original rock. The material between the quartz bands is finely flaked sericite. Small pyrite grains are enclosed by both quartz and sericite, and were probably formed at the time of the alteration of the rock. A large number of dusty inclusions in the quartz are fine pyrite and iron oxide. White secondary quartz is sometimes developed in small lenses and veinlets, which sometimes interfere with the continuity of the flow lines, and sometimes crowd them apart.

In the eastern part of the Tonopah Mining Company's property is found a rock somewhat similar to that just described. In this rock the flow lines are wavy and well marked, but the color varies from gray to a decided pink. In thin section it is seen to be murky with decomposition products. No evidence of phenocrysts is seen in the single section made of this rock. In the hand specimen there are a few imperfectly rectangular casts filled with a whitish substance which is specked with hematite. These are suggestive of former phenocrysts, but there are many holes in the section, and if there were any of these casts in the specimen they were lost in preparing the section. The flow laminæ are closely spaced and are alternately secondary quartz and a white opaque substance. Minute flakes of sericite are sparingly disseminated over the slide. Numerous specks of red hematite show that the red color of the rock is due to that mineral.

These rocks showing flow structure have not been analyzed, but from their general characteristics are thought to be rhyolites, and are considered stratigraphically as a part of the upper rhyolite flow. They are probably flows which preceded the main body.

The upper rhyolite is well exposed in the Midway mine. In this locality the upper parts of the sheet are light green rhyolite

of the normal type, but the lower parts as found north of the shaft vary from a dense white rhyolite to a rhyolite breccia, composed of angular rhyolite fragments with sharp borders, set in a paste of white rhyolite or impure quartz. This rock is quite different from what has been described as the normal type of rhyolite. It seems to be much more siliceous. The exposures of this rock on the 835-foot level of the Midway mine show that it overlies the calcite andesite, and it is therefore mapped with the upper rhyolite. Much depends upon the correct explanation of the history of the upper rhyolite. In view of the fact that it was classed by Spurr as intrusive, it occupies an important position with respect to the present argument, and the evidence concerning its origin will be reviewed at length.

The upper rhyolite was either poured out in a liquid state from a volcanic vent upon an older surface formed mostly of the calcite andesite, and then covered with the earlier andesite; or it was forced in a molten state, under tremendous pressure, into a body of andesite older than itself, splitting it into two comparatively horizontal sheets, as represented by the calcite andesite and the earlier andesite. The latter idea, that the upper rhyolite is intrusive into an "earlier andesite," is the one commonly held, and it will be discussed first.

Intrusives of this character, known as sills, are common where sedimentary rocks are penetrated by igneous intrusives. In such occurrences the igneous rock is forced in the molten state, under great pressure, along the bedding planes between the horizontal sedimentary strata; and it is simply a case of a fluid under pressure escaping along the direction of least resistance. Likewise there are sheeted intrusions along fault-planes, and also dikes in either sedimentary or igneous rocks. But in either of these cases, where the thickness of the intrusive body is great, the disturbance of the enclosing rocks by the intrusion results in the formation of cracks, into which the intrusive rock is forced, thus forming the tongues which are characteristic of intrusives. The adherents of the intrusive theory may argue that the intrusive could have followed a horizontal fault plane. To this it may be answered that a horizontal fault of this extent is not consistent

with the complex volcanic structure of the Tonopah district, and that it is unlikely that an intrusive 300 feet thick in places could follow such a fault without rupturing the overlying rock and forming unmistakable tongues or apophyses. Such tongues are not in evidence. Features which are sometimes mistaken for them may be accounted for by faulting. If the upper rhyolite were intrusive it should show a better developed porphyritic structure than it does. On the contrary its lack of crystallization is more characteristic of a thin surface flow than of an intrusive. Thus far it has been shown that the upper rhyolite fails to possess the usual characteristics of intrusives. The ways in which it resembles a surface flow will be taken up next.

In reviewing the positive evidence in favor of this rhyolite being a surface flow, the strongest support is found in its shape and position, as shown in the sections. It is there shown as a tabular body of rock of fairly uniform thickness, underlying the earlier andesite. Its irregularities may be accounted for in a great degree by the folding and faulting that has affected the region since its outflow. The boundary of its upper surface has been fairly well ascertained; and although less is known of its lower surface, it is thought that there is sufficient evidence to warrant the belief that its shape is approximately as shown in the sections. However, as indicated on the drawings, a distinction has been maintained between known boundaries and those that are inferred. This is true of all the contacts shown. As far as the writer knows, this sheet of rock is coextensive with the earlier andesite throughout the producing area of the camp. Wherever mine workings within these limits are known to have penetrated below the earlier andesite the underlying rock has proved to be the upper rhyolite. Judging from the criterion of position and shape alone it seems that the most natural explanation of this rock is that it was laid down as a flow-sheet.

The contact phenomena, where visible, are also in favor of this view. Original contacts in such cases are usually decisive as to the relation of the rocks; but here, in by far the greater number of exposures, they are so obscured by alteration or by faulting that they give no information as to their original character.

There are, however, some indications of considerable importance. In a number of places a pyroclastic breccia several feet thick, consisting of sharply angular, firmly cemented fragments, has been observed lying between the upper rhyolite and the earlier andesite. If this breccia had been formed as a contact breccia on the borders of an intrusive mass the fragments should consist solely of pieces of the older rock incorporated in the borders of the intrusive. On the contrary, the fragments in the breccia are of various kinds of rock; some of them are andesite, though different from the earlier andesite, and others are of various rhyolitic rocks, different from the upper rhyolite. Some of them show well marked flow-structure and some contain numerous quartz phenocrysts. Both fragments and cement are altered. There is an excellent example of this in the MacNamara mine. The breccia is there found lying on top of rhyolite, which is undoubted upper rhyolite. The contact of this breccia with the rhyolite is usually distinct, but in several places in the Tonopah Mining Company's property the breccia has been found merging gradually into the earlier andesite. Breccia of this character is not found everywhere on this contact, but it has never been found in any other position than at the contact. It seems impossible to explain it in a way that is consistent with the idea that the rhyolite is intrusive; but it can readily be explained as an accumulation of fragments that lay upon the surface of rhyolite at the beginning of the andesite flow, and which were cemented into the lower surface of the andesite; or it may be explained as a thin breccia flow immediately preceding the andesite. It may be that the breccia had its origin in explosions that initiated the andesite eruption. A photograph of a specimen of this breccia is shown in Fig. 85.

Spurr correlated the upper rhyolite with the extensive surface flow of "rhyolite dacite," and also with the rock below the 900-foot level of the Mizpah shaft. In the light of evidence now available it does not seem that this relation can exist. The rhyolite-dacite on the surface is a rock of different appearance from the upper rhyolite, and lies above the later andesite, which is undoubtedly of later origin than the main veins. In many

places these veins extend downward into the upper rhyolite, and where this rhyolite forms one or both walls of the veins angular fragments of rhyolite are found included in the vein. These facts show that the upper rhyolite is older than the veins, and that the surface rhyolite-dacite is younger than the veins. As

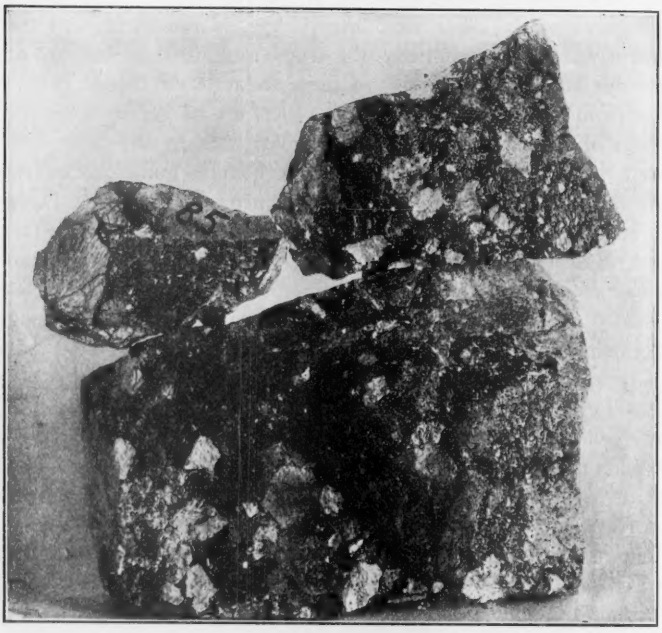

FIG. 85. Breccia from MacNamara Mine. It lies between the earlier andesite and the upper rhyolite. Breccia similar to it is found in many places on this contact. Length of large specimen, 8 inches.

regards the correlation of the upper and lower rhyolites, their physical characteristics are totally different, as evinced by their detailed descriptions. In this paper the name rhyolite-dacite is applied only to the surface rock.

Briefly, the chief evidence showing that the upper rhyolite is a flow sheet is as follows:

1. The horizontal tabular form of the body.
2. The absence of apophyses.
3. The petrological character of the normal rock. Its probable original glassy structure is a surface type.
4. The presence of various distinct types of rock within the sheet.
5. The character of the breccia between the upper rhyolite and the earlier andesite.
6. The failure to correlate the rock with the surface flow of rhyolite-dacite, or with the lower rhyolite.

EARLIER ANDESITE.

The earlier andesite, frequently called the lode-porphyry, is by far the most important of these rocks with respect to ore-formation. It outcrops at the surface on the Tonopah Mining Company's property and on Gold Hill. Elsewhere it is covered by the capping of later andesite. Its petrological characteristics have been well described by Spurr and will not be enlarged upon here. It will be sufficient to say that it is an altered hornblende andesite. Where not covered by the later andesite the earlier

ANALYSIS OF THE EARLIER ANESITE.

SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	CO_2	FeS_2	H_2O	Total.
64.50	16.82		1.08	1.76	3.00	3.80	1.77	5.70	1.63	100.04

andesite has usually a yellow or pink tinge, or is sometimes white or light gray. The light shade of the rock is due to the leaching out of the greater part of its iron content, and the colors are due to the ferric condition of most of the remaining iron. Where it is covered by capping the earlier andesite has a green appearance due to the presence of such alteration products as chlorite and others minerals containing iron in the ferrous condition. In some places, even where covered by capping, the earlier andesite is leached and oxidized, suggesting that this action had taken place to some extent prior to the later andesite flow. This coincides with the supposition that the surface of earlier andesite suffered erosion before being covered by the succeeding flow; a belief that is supported by the sharp termination of some of the

veins of the earlier andesite at the lower surface of the capping. In composition the earlier andesite closely resembles the calcite andesite, and specimens from some parts of the earlier andesite are very much like the calcite andesite; but the ordinary type of earlier andesite is marked by phenocrysts somewhat larger than those of the usual type of the calcite andesite. However, the distinction between the two on this basis would be uncertain, and the only trustworthy distinction is in their position with respect to the upper rhyolite. Calcite can be found to some extent in any of the rocks of this district.

The earlier andesite extends with no other known interruption than faulting throughout the entire ore-producing region; and it undoubtedly extends to much wider limits than where it is now known. The difficulty in distinguishing it from the later andesite may account for its not being recognized in some of the outlying mines, although probably many of them have not attained sufficient depth to reach it. It seems that in the search for the ore-bearing formation, the earlier andesite, in these mines; the best means for determining it would have been by diamond drill holes driven to ascertain the kind of underlying rock. While this might not give conclusive evidence in all cases, it would undoubtedly be a help; for example, if andesite resembling the earlier variety were in doubt, and a drill-hole encountered rhyolite below it resembling the upper rhyolite, the rock immediately above the rhyolite might reasonably be thought to be earlier andesite. It is not to be thought, however, that the succession of rocks as found in the producing district is necessarily the same over an extensive area, since lava flows are characteristically irregular.

The marked variation in thickness of the earlier andesite is doubtless due chiefly to erosion. It is noteworthy that the thicker portions are those of greater silicification and vein formation, and consequent greater resistance to erosion. The irregular outline of the sections of the andesite, especially noticeable in Figs. 82 and 83, does not seem to be fully accounted for by faulting, and it seems that both folding and faulting have been involved in its deformation. The Mizpah fault-contact, as shown in Fig. 81,

best expresses this idea. It seems to be a monoclinal fold faulted at the bend, although, as a matter of fact, the movement is more complex than this statement indicates. As seen in Fig. 80, the strike of the fault does not form a right angle with any of the sections. The movement is not directly downward on the dip of the fault, but as shown by striations on the slickensides and the lag of the adjacent fault-blocks, the horizontal component of the movement to the right, looking east, is nearly as great as the component downward on the dip. This kind of movement is characteristic of most of the faults east of the Mizpah shaft, many of which are not shown in the sections. They undoubtedly represent the slipping planes of fault-blocks that were dragged short distances by the motion of the Mizpah fault. It should be kept in mind in viewing the sections that the faults represented are seldom normal to the section, and that the blocks above the faults have seldom moved directly downward on the dip. This helps to account, in some cases, for the apparent inconsistence in the thickness of the same rock on different sides of a fault. In Fig. 80 the thinness of the earlier andesite, west of the Burro fault, is explained by the probable presence of an erosional trough. The downthrow of the Burro fault at this place, the amount of which is established by the displacement of the lower surface of the earlier andesite, is not sufficient to account for the presence of the great thickness of later andesite west of the fault, and it is probable that when the later andesite flow began there was a hollow at this place. The Burro fault then occurred in part along the eastern side of this hollow; or perhaps there was movement on the fault both before and after the later flow. At a point further west, in the MacNamara mine, the earlier andesite at the top of the anticline is not over twenty feet in thickness.

PRODUCTIVE VEINS.

As before intimated, the importance of the earlier andesite lies in the association of the ore-bodies with it. It is not intended to give here a full description of the ore deposits of Tonopah, but this article would not be complete without an outline of their general character. It is thought that the following statement is

not too comprehensive; that all the known productive veins of Tonopah lie in one of these positions:

1. With both walls of earlier andesite.

2. With hanging wall of later andesite and foot wall of earlier andesite.

3. With hanging wall of earlier andesite and foot wall of upper rhyolite.

4. With both walls of upper rhyolite, usually having descended successively through positions 1 and 3.

These are more specifically described as follows:

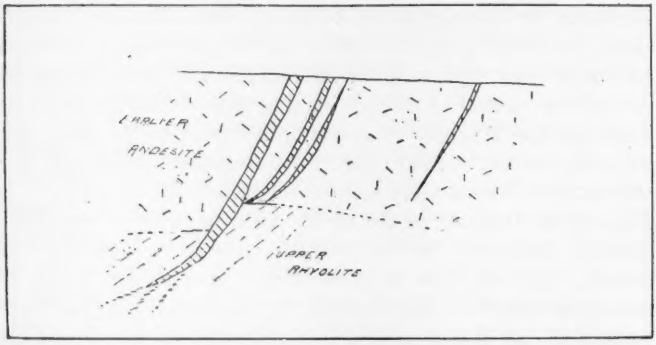

FIG. 86. Diagrammatic representation of a typical vein system.

1. The larger veins of the camp in their upper parts and many of the smaller veins through their entire extent.

2. A deposition of ore on the Mizpah fault contact, sometimes sufficiently continuous to be called a vein; and in other places bunchy or of lense-like form. This ore is apparently later than the main veins.

3 and 4. As shown diagrammatically in Fig. 86, most of the large veins descend without change of character through the following positions: first with earlier andesite on both walls, next with earlier andesite on the hanging wall and upper rhyolite on the foot wall, then with upper rhyolite on both walls. In this last position the vein may continue of good value for a consid-

erable distance into the rhyolite, but it usually deteriorates in both strength and value as it gets further into the rhyolite; and the quartz disappears, not so much by pinching out, as by merging in a frayed-out manner into the wall-rock. Frequently a quartzose zone can be traced for a considerable distance into the rhyolite. The vein often flattens as it enters the rhyolite. In some places the vein ends abruptly on the contact, but in most of such cases there are signs that there has been movement on the contact, and that the veins are faulted. The writer has not seen a single instance of a vein having been cut off at an intrusive contact. Spurr gives a map of the 800-foot level of the Desert Queen shaft, showing a vein all in rhyolite. The rock in which this vein lies is really earlier andesite. There is a block of andesite over 300 feet thick under the Mizpah fault at this place, as shown in Fig. 81. The section passes along the vein shown in Spurr's map. The vein has been opened up continuously through the andesite and has been shown to be the extension of the Mizpah vein. There are some barren veins entirely in the upper rhyolite which seem to have no connection with the ore-producing veins. The West End-MacNamara vein lies almost entirely on the rhyolite-andesite contact. The veins are undoubtedly replacement veins, the replacement occurring mostly in the foot wall and in the fragments of the crushed zone. They carry silver and gold uniformly in the proportion of 90 to 1 by weight. The gangue is mostly quartz.

LATER ANDESITE AND OTHER LATER FORMATIONS.

The later andesite immediately overlies the earlier andesite. It is similar to the earlier andesite, but was originally of slightly more basic composition. In some places it can be found almost perfectly fresh, but it is usually intensely altered. Its appearance underground is that of a dark green, altered, porphyritic rock; which in places is indistinguishable from the green variety of earlier andesite. It is known to be several hundred feet in thickness within the territory under discussion, and it is doubtless of much greater thickness outside of this district. It forms a surface flow of large extent and is found for a radius of several

miles surrounding Tonopah. It is covered by later lavas and tuffs in many places. It is not known to contain ore, although poorly defined and non-continuous stringers and bunches of quartz, assaying a few dollars per ton in silver and gold, have occasionally been found in it. On the surface the earlier and later andesites are easily distinguished, but in many places underground alteration has rendered them so much alike that sometimes the most trustworthy basis of distinguishing them is by the presence or absence of ore in veins or small stringers.

The rocks lying above the later andesite are not of economic importance within the ore zone, but inasmuch as they consistently carry out the scheme of the upbuilding of the terrane by lava flows and tuffs, they will be briefly mentioned.

The later andesite was followed by a series of surface flows of rhyolites and breccias, which Spurr has segregated into the Heller dacite, Fraction dacite breccia and the Tonopah rhyolite-dacite, with accompanying tuffaceous material. These were followed by the formation of the Siebert Lake and the accompanying deposition of the Siebert tuff-beds. After the disappearance of the lake there was a period of erosion. The tuffs were then covered, in some places, with a thin flow of basalt. Then followed the outburst of rhyolitic lavas which formed the mountains, Butler, Siebert, Oddie, Golden and Ararat. Spurr was of the opinion that these mountains were the necks of volcanoes which did not overflow. There has been considerable doubt in the writer's mind regarding this, and the question arose as to whether the mountains could not be considered as the remnants of a rhyolite capped plateau. This conception of their origin is strongly suggested by several mesa-like features of the landscape and certain evidence from underground workings. On the other hand, unquestionable evidence of intrusive contacts can be found on the eastern side of Mt. Butler, on the southwestern side of Mt. Brougher, along the western flank of the Mt. Golden range and on the northern side of Mt. Oddie; and also the rock of Mt. Oddie differs in appearance and slightly in composition from that of Mt. Butler and Mt. Brougher. The conclusion finally reached is that these mountains are remnants of a plateau and that

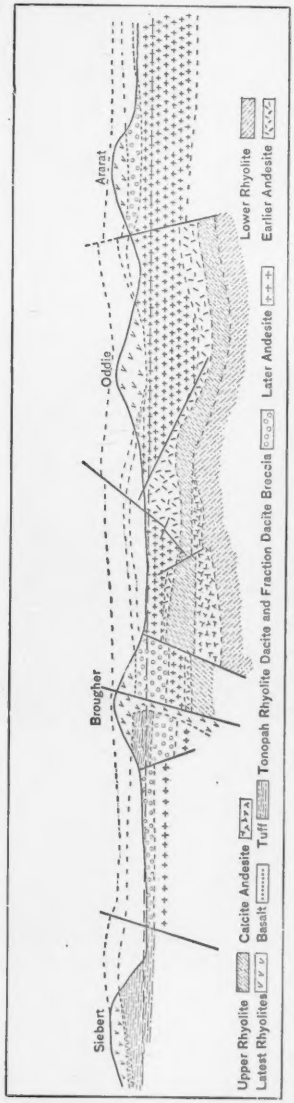

FIG. 87. Idealized section of the Tonopah District, looking North. Illustrating conditions at the close of the volcanic period. The contacts underground are not intended to be accurate.

some, if not all of them, lie over the vents from which the lava that formed the plateau flowed. A section illustrating the writer's conception of the original situation of this plateau is shown in Fig. 87. The evidence bearing upon it is as follows:

1. The surface of Mt. Ararat, part of Mt. Siebert and the small mountain west of Mt. Siebert are of mesa-like form, as shown in the photographs in Figs. 88 and 89.

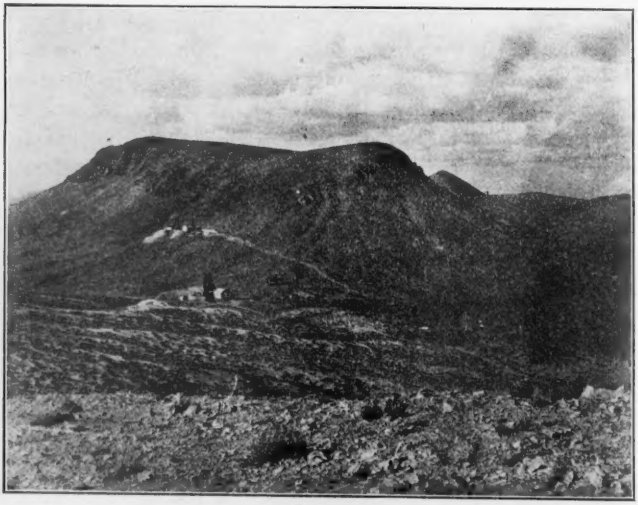

FIG. 88. Looking North, showing Mt. Ararat in the character of a plateau remnant. The surface of the mesa is rhyolite resting on Tonopah rhyolite-dacite.

2. The contacts of the rhyolites with the underlying rocks of Mt. Siebert, the western half of Mt. Butler, the western half of Mt. Brougher, and the mountain two miles south of Butler, are approximately plane surfaces, nearly horizontal, and usually follow the contours, or cross them at a uniform angle, except where they are faulted (see Figs. 89 and 90). This can be well seen in Spurr's geologic map of the district, and also in the photographs accompanying his report.

FIG. 89. Looking South. Mt. Brougher on the left, Mt. Siebert on the right, in the character of plateau remnants. The dark upper rock is rhyolite. The Siebert tuff shows white on Mt. Siebert. On Mt. Brougher it is mostly covered with detritus, but the tunnel at the white dump is in horizontally bedded tuff.

3. Flow laminæ, parallel to the supposed plateau surface, are found where the mesa-like form is most pronounced, as on the western side of Mt. Brougher and on the hills north of Mt. Siebert; and a horizontal stratification, as though due to a succession of flows of the rhyolite lava, can be seen on the north side of Mt. Brougher. This appears in the photograph of Fig. 89.

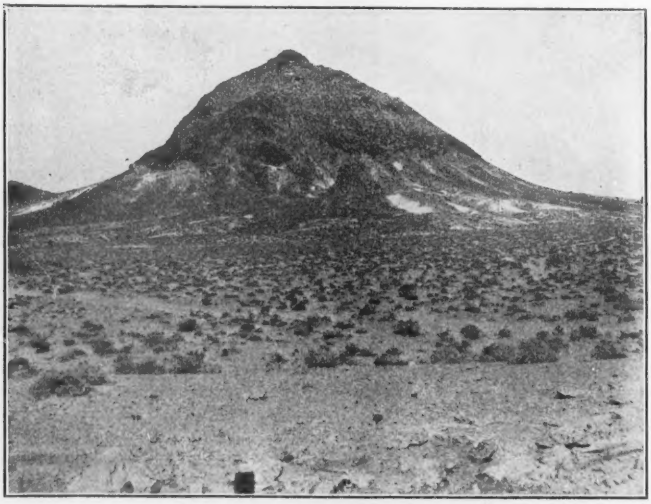

FIG. 90. Looking East at Mt. Brougher, showing the rhyolite resting on tuff.

4. On the 1,000 feet level of the Desert Queen shaft a cross-cut has been driven from a point between the desert Queen shaft and the North Star shaft to a point directly under the Belmont shaft, and although it passes under the southern shoulder of Mt. Oddie it has encountered no rhyolite like that of Mt. Oddie, and none at all except the upper rhyolite. Farther to the north, on the 800 feet level of the Mizpah Extension shaft, rhyolite closely resembling that of Mt. Oddie is found apparently intrusive into andesite, and with contacts dipping to the east or north east. Also the contacts of a small rhyolite intrusion with similar dip is

found at the mouth of the North Star tunnel on the north side of Mt. Oddie. It is thought for these reasons that the vents from which the Oddie rhyolite issued are at the north and east sides of the mountain, and are not vertical, but incline downward to the north or northeast.

Although the Siebert tuffs were covered with lava flows wherever they have come under the writer's observation, that is, for a radius of several miles about Tonopah, the capping was not always rhyolite. Three miles east of Tonopah there is a broad mesa, the surface of which is a sheet of olivine basalt of considerable thickness. It lies upon Siebert tuff and does not seem to have been covered with rhyolite. Two miles south of Golden Mountain a similar basalt forms the summit of the range. West and north of Mt. Siebert the rhyolite is now a thin sheet and probably was never as thick as it is on the higher mountains. It would seem then that the viscosity of the rhyolite, at the time of its effusion, was too great for it to spread to any great extent, probably not over a mile or two from its vents.

FAULTING AND FOLDING.

The faulting of the region is intense. Only the more important faults are shown in the sections, or mentioned here. They are most numerous in the earlier and later andesites and decrease progressively as depth is attained. This is due to the softer, altered condition of the higher rocks.

The Mizpah fault has already been described. For a distance of several hundred feet from it the faults in the earlier andesite are subject to its influence, and although usually steeper their strike is approximately parallel to it. The greater steepness of the minor faults is the natural result of the two-fold nature of the Mizpah fault and is caused by the downward pressure due to the bending. The significance of this bending is brought out by the reappearance of the later andesite at the surface east of Mt. Oddie and Rushton Hill, and although the position of the andesites under the rhyolite just east of the Belmont shaft has not yet been revealed, the situation as known suggests that Mt. Oddie lies in a depression and that the Mizpah fault is the distorted

original contact between the earlier and later andesites. The depth of the depression is doubtless accentuated by faulting.

The displacement of the faults is usually not great. The greatest measured movement is on the Stone Cabin fault, which has a downthrow of about 800 feet, as measured by the displacement of the upper surface of the upper rhyolite; a fact which shows that before the faulting the Siebert tuff lay about 400 feet above the collar of the Silver Top shaft. The majority of the faults have a displacement of from one to fifty feet. The hindrance to mining offered by the faults is due chiefly to the uncertainty of their movement and to the complication introduced by cross faults. An instance of this is seen in Fig. 81, which shows that the Burro Fault fails to cut the 500 feet level where its presence is indicated by its position on the upper levels. It is equally common and surprising to find a large fault where none is expected. The wavy character of the upper surface of the upper rhyolite, as shown in Fig. 83, may be explained in part by a warping of the region. The warping is also revealed by other evidence than the position of the rock. The low dip angles of the faults must be explained otherwise than by assuming them to be simple gravity faults. Some of them, especially those at the upper contact of the upper rhyolite, or in the earlier andesite not far above it, are flat or nearly so. These faults would be the natural result of the folding of a region built up of thin sheets. It would correspond to the slipping of playing cards upon each other if the deck is held in the hands and bent. The comparison is not strictly accurate, since the rock sheets have not the tenacity of paper, and would often fracture at even a moderate bend; but this very fact is thought to account for the notched upper surface of the rhyolite at the bends.

A striking instance of folding is found in the West End-MacNamara vein, which lies mostly on the contact between the earlier andesite and the upper rhyolite. The contact here forms a pronounced anticlinal fold with its axis running about S 60° E and pitching downward at a small angle to the east. It does not show on the sections. The hanging wall of the vein bends with hardly a break over the axis of the fold and dips irregularly at an angle

of from 20° to 40° on either side. Other evidence of warping and twisting is found in the striations on most of the faults, which run at angles as great as 60° from the dip, and show a large lateral movement.

SUMMARY OF GEOLOGICAL HISTORY.

Summarizing, the district is composed of a faulted and eroded series of flow sheets and tuffs, with periods of erosion between some of them. If the sequence and manner of deposition is correctly interpreted here, the surface immediately after the outflow of the Oddie rhyolite and the Brougher "dacite" consisted of a broad and probably slightly domed plateau, and the rhyolite forming the surface near Tonopah was thickest in the vicinity of the present higher mountains. Faulting played a part in the degradation of the region. As Spurr has stated, the region was much faulted at the close of the Siebert Lake period. There is also a series of faults that occurred after the completion of the volcanic period and intersected the rhyolite capping. The greater part of the erosional deformation of the plateau was probably accomplished during a period of heavier precipitation than the present, and once erosion had cut channels through the rhyolite it made rapid progress by wearing away the soft, faulted, underlying rocks and undermining the capping. At the present time erosion is proceeding in the slower manner characteristic of arid regions.

GEOLOGIC COLUMN.

The following tabulation shows the sequence of the volcanic formations in descending order:

Rhyolites.
    Oddie rhyolite, Brougher dacite, etc.
Basalt.
Siebert tuff beds.
Rhyolites and rhyolite-breccias.
    Heller dacite, Fraction dacite-breccia, Tonopah rhyolite-dacite.
Later andesite.
Earlier andesite.
Upper rhyolite.
Calcite andesite.
Lower rhyolite.

If it can be considered established that the Tonopah terrane is built up of a series of superimposed tuff-beds and lavas as here proposed, the structure of the district then harmonizes well with the general geologic structure of this portion of Nevada; and it is of interest to compare the succession of rocks in the Tonopah District with that reported by Sidney H. Ball for southwestern Nevada.[1] The occurrence of Siebert Tuffs in both columns forms the basis for the correlation shown in the following table. The considerable thickness of the lower rhyolite of Tonopah suggests its correlation with the second rhyolite in Ball's column, which he describes as the rhyolite flow of greatest volume. The other Tonopah lavas then fall naturally in the places assigned them. Although the adaptation of the Tonopah rocks to Ball's column seems satisfactory, the fact is recognized that there is too little evidence for an assured correlation, and this comparison is offered only as a suggestion of a possibie agreement in the succession of flows.

TABLE.

S. H. Ball's column for Southwestern Nevada.			Tentative correlation with the Tonopah Rocks.
Tertiary	Pliocene	Rhyolite	Oddie Rhyolite Brougher Dacite
		Siebert Tuffs	Siebert Tuffs
		Rhyolite	Rhyolite Dacite Fraction Dacite
	Miocene	Basic Andesite	Earlier and Later Andesite Upper Rhyolite and Calcite Andesite
		Second Rhyolite	Lower Rhyolite
	Eocene	Monzonite Porphyry and Acid Andesite	Fragments of andesite and rhyolite in the Lower Rhyolite
		First Rhyolite	

[1] U. S. G. S. Bull., 308. 1907.

THE BREWSTER IRON-BEARING DISTRICT OF NEW YORK.[1]

F. R. KOEBERLIN.

CONTENTS.

General Geology 713
Introductory 713
Geography and Topography 715
Outline of Geology 716
Gneiss (Fordham) 716
Sedimentary Group 718
Granitic Group 722
Syenitic Group 724
Limestone (Inwood) 728
Schist (Manhattan) 730
Dioritic Intrusion 733
Pegmatite Dikes 737
Glacial Drift 738
Economic Geology 738
Descriptions of the Mines 738
Tilly Foster Mine 738
Croton Mines 743
Brewster Mines 746
Prospects 746
Discussion 748
Economic Considerations 752
Bibliography 754

GENERAL GEOLOGY.

INTRODUCTORY.

The area described in this paper is one that was well known to geologists and mineralogists of the seventies and eighties, as it was then the seat of an active iron-mining industry. At the present time, however, none of the mines are working and but little has been heard of the district during the last decade.

[1] Submitted in partial fulfillment of the requirements for the degree of Master of Arts in the Faculty of Pure Science, Columbia University.

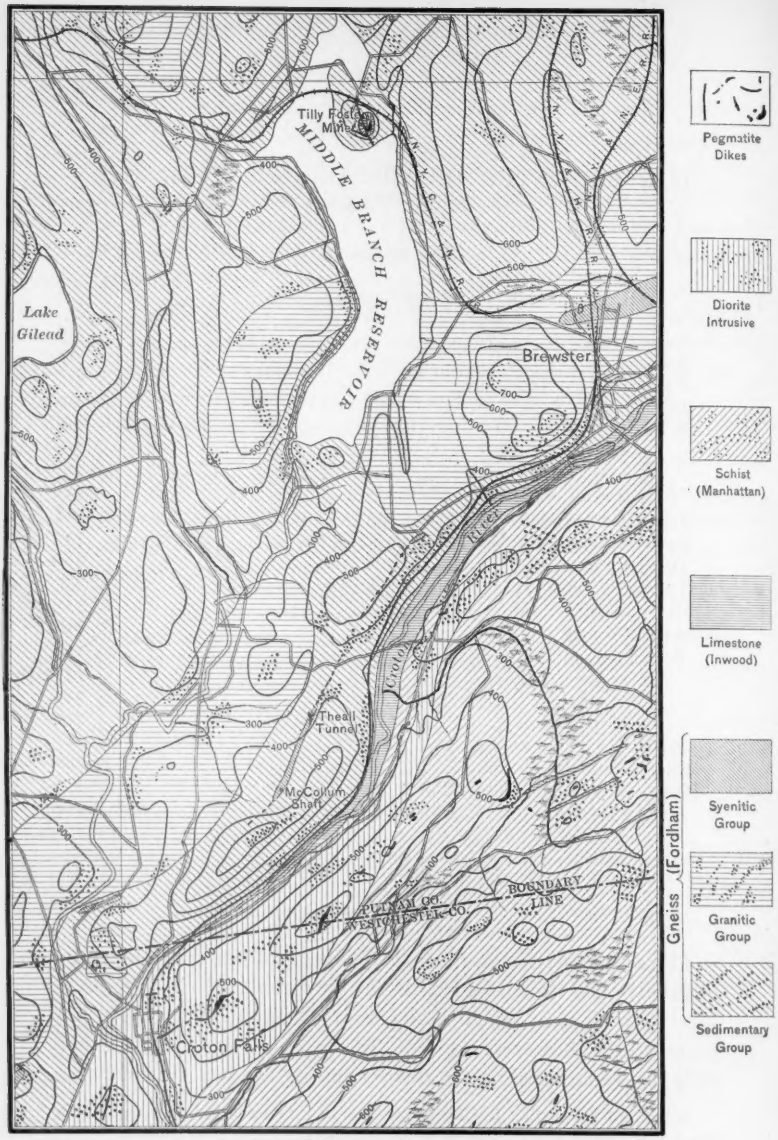

FIG. 91. Geological Map of Brewster Iron-bearing District.

The geology of the region has never been studied in any great detail, although at the time that mines were operating, the local structure received some attention, yet very little work was done on the broader problems of the genesis of the ore-bodies, or their relationships to the surrounding geological formations. It was with the idea that a petrographic study of the rocks in the territory immediately contiguous to the mines might throw some light on these larger problems that a few weeks were spent in this neighborhood, mapping the areal geology and collecting specimens for petrographic study. The base of the map was the U. S. G. S. Topographic sheet of the Carmel quadrangle, New York, while as a guide to the general geology of this part of the state Merrill's map of southeastern New York as well as a recent paper by Dr. C. P. Berkey, in Bulletin 107 of the New York State Museum, were very useful.

In this connection the writer takes the opportunity of acknowledging his indebtedness to Dr. C. P. Berkey, who spent some time in reviewing the work in the field and in the laboratory; also to Professor J. F. Kemp, who kindly permitted the use of his slides of the Croton mine ores, and gave the benefit of many helpful suggestions.

GEOGRAPHY AND TOPOGRAPHY.

The area to which the work was confined is a rectangle six miles north and south by three miles east and west. It includes the Tilly Foster mine near its northern boundary, the small city of Brewster near the eastern, and the village of Croton Falls near the southern boundary. Brewster and Croton Falls are located on the Harlem branch of the New York Central and Hudson River Railroad, the former being fifty-two miles from New York City.

Topographically, the area plainly shows the effects of glacial action, in the irregular distribution of hills and valleys and in the evidences of obstructed drainage such as lakes, swamps, crooked and reversed streams with unequal gradients, etc. The natural topography has been and is being greatly modified by the works

of man. Probably one-third of the area considered in this paper has been bought up by the city of New York for the purpose of protecting its water supply; and when the dams and reservoirs which the city is constructing are completed, most of the valleys and swamps in the area will be under water. The limits of elevation are 781 feet for the highest point on the hill just west of Brewster and 200 feet for the lowest in the Croton River valley below the Croton Falls.

OUTLINE OF THE GEOLOGY.

The oldest formation exposed in the area is a complex series of pre-Cambrian rocks which has been shown to be practically continuous with the Fordham gneiss of the Harlem quadrangle, and which constitutes the principal rock mass making up the range of mountains known as the Highlands of the Hudson. From evidence outside of this quadrangle it is believed that the gneiss is uncomformably overlain by a formation of crystalline, dolomitic limestone, known as the Inwood limestone further south. Limestones are exposed in a number of places in the area, but they are small beds interstratified with gneiss or schist. Next in chronological order above the Inwood limestone is the Manhattan schist. The schists form a prominent part of the rock mass exposed in this quadrangle, and in this case also there can be but little doubt that they are identical with the formation known as the Manhattan schist in the Harlem quadrangle. Finally, a mantle of glacial drift covers most of the area, leaving the underlying formations exposed only in places. This purely surficial covering is not taken into account on the map, which shows only the hard geology as interpreted from the exposed outcrops.

THE GNEISS (FORDHAM).

This is a general collective term for that exceedingly complex series of metamorphic rocks which runs the whole gamut of variations from a micaceous schist at one extreme to a massive granitoid rock at the other. As exposed in this quadrangle, which is typical of the Highlands, the banded varieties are most common.

The bands are caused by the alternation of light-colored feldspathic and quartzose layers with darker ones heavy in the ferromagnesian minerals. Sometimes the bands grade imperceptibly into each other, then again the boundaries are sharp and well defined. They may be parallel for long distances, or one series may cut across another.

Both igneous and sedimentary members undoubtedly go to make up the original rock mass, but the relations of the several kinds of rock have been enormously complicated by the distortion caused by folding, faulting and crushing, combined with the effect of later intrusions, erosio intervals, alteration and recrystallization. The complexity of these relations can hardly be exaggerated, and has given rise to such terms as " basement complex, " fundamental complex," etc. In any small area one may find variations almost without number, and yet if compared with other like areas the difference between them does not seem to be so great. There is a certain constancy in the inconstancy of the chemical and mineralogical constitution of the series, in the sense that the variations in any one area are very much the same as in any other.

It was thought desirable for the purpose of this investigation to attempt to differentiate the igneous from the sedimentary members, although recognizing that this was possible only in the roughest sort of way. But even where it was possible to determine the original condition with a reasonable degree of certainty, it was found that the two series were so closely intermingled that it would be impossible to map them separately on a small scale. Consequently, it was thought best simply to subdivide the gneisses into groups, the basis of the division being the dominance of some particular rock type, but not necessarily to the exclusion of the others.

On this principle it was possible to subdivide the gneisses into three groups, each group having some distinctive mineralogical or structural characteristics, and having sufficient extent areally to justify mapping. The three groups are:

1. The Sedimentary Group, which embraces also all the interlaminated igneous members too small to be mapped separately.

2. The Granitic Group.
3. The Syenitic Group.

The Sedimentary Group.

General Character.—There can be but little doubt that the oldest gneissic rocks exposed in this area are sedimentary. Nowhere was any considerable mass of igneous rock found which might have served as a basement on which the sedimentaries were laid down, and in all cases where a contact between undoubted sedimentary and igneous rock was observed the latter was always intrusive. The criteria upon which identification of a sedimentary rock in the large way was based were these remaining traces of stratification, interbedded limestone or its derivatives, interbedded quartzite, graphitic or highly quartzitic schist. Not much faith was placed in apparent stratification, as instances were numerous in this quadrangle where a massive igneous rock could be traced step by step into a sheared and banded alteration of the same. Only when the banding was unusually regular and persistent was it taken as indicative of stratification, provided other facts did not conflict with this interpretation. Bedded limestone, however, was accepted without further question as of sedimentary origin, *i.e.*, either an organic or chemical deposit. Bedded quartzite and graphitic schist were not positively identified in the large way, and it was generally not attempted to interpret any schist without the aid of the microscope.

The intermingled igneous members were identified by their structural relations to the undoubted sedimentaries, or by some peculiarity of mineralogical constitution. They most frequently occur in the form of highly feldspathic, pegmatitic lenses, or as amphibolite dikes and sills. It was seldom, however, that conclusive evidence could be brought to bear on their origin, and the so-called sedimentary group must on the whole bear a greater proportion of the irresolvable elements than the other two.

Microscopic Character.—The purest limestone found in the gneiss was a bed about half a mile north of the Tilly Foster mine. The rock consists of a mass of rather coarse interlocking

crystals of calcite, speckled with grains of a pale green amphibole and diopside. The amphibole is derived from the diopside, as is shown by some grains which still have a diopside core. At the mine itself the immediate country rock was a limestone which has been almost entirely replaced by contact minerals. This rock will be more fully described further on. North of Croton Falls several thin beds of crystalline limestones are exposed in the railroad cuts. These are all highly altered, calcite being largely replaced by scapolite, pale green pyroxene, quartz,

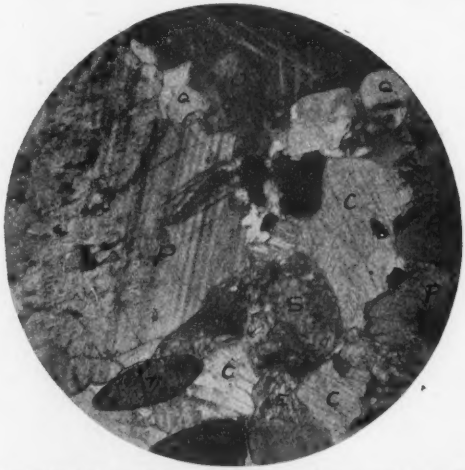

FIG. 92. Interbedded limestone from railroad cut north of Croton Falls. *C*, calcite; *P*, pyroxene, some of it showing twinning; *Q*, quartz; *S*, scapolite; *O*, orthoclase; *E*, epidote; *Py*, pyrrhotite. Crossed nicols. Magnified 30 diameters.

orthoclase, epidote and titanite (Fig. 92). The calcite crystals form a ground mass in which the grains of scapolite and light green pyroxene are set. These two minerals with titanite and pyrrhotite seem to have been developed from the material of the original limestone, or by the action of contact metamorphism. The quartz and orthoclase on the other hand were introduced along lines of fracture and are probably a later de-

velopment. Hornblende is a derivative from the pyroxene, and the epidote is also apparently secondary.

In the banded rocks bordering on these interbedded limestones, one would naturally look with greater confidence for evidences of original sedimentary condition, and such rocks do often show characteristics that can reasonably be interpreted as pointing to a derivation from shales, sandstones, etc. The most suggestive rocks of this kind were made up of a fine-grained mass of orthoclase, quartz, green biotite and hornblende, and a little acid plagioclase. The banding is due to the schistose alignment of the green biotite and hornblende. The order of crystallization that usually obtains with igneous rocks is not apparent here, quartz often being included in feldspar while the ferromagnesian minerals mold themselves to both quartz and feldspar. In some instances the included matter in quartz was very abundant and arranged in curved lines, such as might be expected when a rounded elastic grain of quartz has been secondarily enlarged, the old smirched surface of the grain being preserved in the inclusions. Euhedral crystals of pyrogenetic minerals like zircon were absent, nor were there in the most typical cases any pyroxene or the brown varieties of hornblende and biotite. The small amount of sodic plagioclase is also significant, in view of the fact that the undoubted igneous rocks in this region carry rather large amounts of albite and microperthite, as will be shown when those rocks are considered. After the distinctive petrographic features of this rock had once been thoroughly noted it could often be recognized even when not directly associated with limestone.

On the other hand, the rock immediately adjacent to an interbedded limestone was not always sedimentary, if indeed in most cases, but frequently gave evidence of having had an igneous origin. The large amount of contact metamorphic minerals in the limestone would in itself presume a nearby igneous intrusion. Such rocks were usually granitic, syenitic or dioritic in their mineralogical composition. Under the microscope it is noted that the feldspathic constituents occur in larger individuals than in the typical sedimentary gneisses. Quartz, if present, usually

occurs interlocking with the feldspars and is not often included by them. It may be clouded by minute inclusions, but they seem to be more evidently localized along lines of fracture and do not show the curved alignment noted before. The order of crystallization, in so far as it can be determined, usually shows the normal sequence of an igneous rock, with the exception of magnetite, which very often seems to be the last mineral to separate from the magna. The anomalous behavior of this mineral may have a bearing on the method of ore formation and will be more fully discussed further on. The ferro-magnesian minerals are not restricted to the green varieties of biotite and hornblende, but also include pyroxenes, both contact-metamorphic and pyrogenetic species. Euhedral and unworn grains of such pyrogenetic minerals as zircon are common.

These igneous bodies are no doubt offshoots from those larger masses to be described under the granitic and syenitic groups, but they are so intimately intermingled with the sedimentary members that it is difficult to decide whether to consider the group as mainly sedimentary but thoroughly permeated by igneous matter, or as mainly igneous with sedimentary masses caught up in it and partially digested.

Distribution.—All that part of the area northwest of the Croton River is taken up by the gneiss. The boundary between it and the succeeding limestones is nowhere exposed, but there is little doubt that it lies below the drift in the river valley, and that the course of the valley itself is largely determined by the position of this limestone formation. In the southern part of the area an intrusion of diorite, which cuts out the limestone, lies next to the gneiss. This contact leaves the river valley at the village of Croton Falls and continues on a southwesterly strike. None of the typical gneiss has been found east of the Croton River.

By far the greater part of the gneiss area has been referred to the sedimentary group, but the strip about a quarter of a mile in width, and contiguous to the limestone and diorite, has more exposures of interbedded limestone and can therefore lay the greatest claim to correctness. The best exposures of interbedded

limestones are in the railroad cuts from one to two miles north of Croton Falls. Another somewhat doubtful occurrence of limestone was noted at the south end of Middle Branch Reservoir, but most of the area between the reservoir and Lake Gilead, and for two miles north and south of the latter, could only be mapped on the basis of the petrographic character of the gneiss outcrops. The block of sedimentary gneiss shown in the northeast corner of the map has some exposures of a garnetiferous gneiss, as well as one good exposure of limestone lying about a half mile north of the Tilly Foster mine.

The strike of the sedimentary gneiss, and of the granitic and syenitic as well, is prevailingly northeast and southwest, an average of about N. 40 E. Great variations from this strike, however, occur locally. In general it may be said that the preglacial topography has adapted itself to this strike, for most of the hard rock ridges trend that way, but there are exceptions to this rule also. The dip where it can be observed is generally vertical.

That more detailed study would show many small igneous areas which could be separated from the sedimentary group is of course beyond question, but most of this area is so thickly covered by glacial drift that its true character will probably never be known.

The Granitic Group.

General Character.—The most striking characteristic of this rock as compared with the gneisses of the sedimentary group is the lack of any very persistent banding. Gneissic structure is marked, but it consists rather in the parallel arrangement of ferro-magnesian lenticles in a feldspathic matrix. Transitional stages to the banded gneisses of course are common, and it is often difficult to decide just where to draw the line. The granitic extreme is an almost pure feldspathic mass, very much like the pegmatite dikes so common in the schist area, to be described later. The color is of a pinkish cast on a fresh surface. It seems to resist weathering better than the more banded varieties, and its outcrops are more prominent. Jointing, though not as

pronounced as in granite, is noticeable. It is a good building stone and several quarries have been opened on this kind of rock. The feldspars and quartz often occur in individuals large enough to be recognizable with the unaided eye, but the identification of the dark minerals requires the assistance of the microscope, especially in zones of shearing where all the minerals have suffered crushing and comminution.

Microscopic Character.—A typical specimen of this gneiss would show in thin section, quartz and orthoclase in about equal quantities, and a somewhat smaller proportion of an acid plagioclase. Hornblende and biotite, the green varieties, with some magnetite and serpentine constitute the dark minerals. Orthoclase may be in part or wholly of the microcline variety, while the sodic equivalent is often represented by microperthite. The largest grains are quartz, orthoclase and microperthite set in a mortar of the same. Aside from the mortar structure, the large grains show the effects of crushing in their wavy extinction, trains of inclusions, etc. The development of microcline seems to be more abundant along the zones of greater crushing. All the light minerals form an interlocking, allotriomorphic aggregate. The hornblende is a bluish green highly pleochroic variety, and is probably uralite, judging from the manner of its distribution, and its occurrence as a ring from which the central core of pyroxene has since disappeared. A further alteration of this hornblende to a brownish yellow opaque mineral probably serpentine is noticed. Green biotite may take the place of hornblende. Especially in the shear zones is there a greater development of biotite, the gneissic structure of the rock being due to the schistose arrangement of this mineral. All of the dark minerals, however, show a more or less parallel arrangement. Magnetite occurs in irregular bunches, usually with some excretions of leucoxene, which would suggest an admixture with ilmenite.

As ilmenite is regarded as pyrogenetic mineral by most authorities, the igneous origin of the rock is indicated. The rock itself has all the characteristics of a deepseated igneous intrusive of a composition about that of a granodiorite. It is probable,

however, that much sedimentary matter has been incorporated and partly digested, and the whole greatly sheared and crushed and recemented by secondary solutions.

Distribution and Age.—The best exposures of this subdivision of the gneiss series occur on the hill west of Brewster, locally known as Simewog Mountain. This block takes in about one square mile. Southwest of this is a somewhat larger area, its longer axis lying in the same direction and apparently a continuation of the first. Two lesser areas lie between the reservoir and Lake Gilead, and one small patch on the hill just north of Croton falls.

This group must be considered later than the sedimentaries, as tongues and offshoots from it ramify through members of the latter in the most intricate way, sometimes cutting across strata though more often intruding between them. Where it contacts on limestone abundant contact minerals are formed in the latter. Its magma probably possessed extreme mobility, in many ways suggesting the aqueo-igneous fusion or solution of a pegmatite magma.

The Syenitic Group.

General Character.—The typical rock of this group is of a dark, grayish green color, and has a coarse-grained, granitoid texture in places not disturbed by shearing movements. Near its boundary with other rocks, however, it usually shows gneissic structure due to shearing. It does not occur in large bodies but rather in elongated dike-like forms. It is a hard, very compact rock on fresh exposures, but seems to weather somewhat more readily than the granitic gneiss. Its appearance in the field is very much like a gabbro. In the smaller exposures the rock seems to have undergone greater alteration, which often greatly changes its appearance. Sericitization of the feldspar and uralitization of the pyroxene have the effect of bringing the light and dark minerals into much greater contrast, and what is a dull, dark green rock in the larger bodies may appear as a bright, white and black mottled rock in the smaller outcrops. Microscopic study alone can determine the true nature of the rock in such cases.

Microscopic Character.—A fresh specimen is made up of nearly one-half orthoclase. Acidic plagioclase normally amounts to about twenty per cent. of the whole, but sometimes the mineral microperthite takes the place of orthoclase and albite-oligoclase and becomes the dominant mineral. It would seem that the composition of the rock as a whole remains unchanged however, for as microperthite increases both orthoclase and albite decrease, apparently being simply a different arrangement of molecules of orthoclase and albite already in the magma. The dark minerals are olivine, pale green pyroxene, hornblende, brown biotite and magnetite.

FIG. 93. Syenite from railroad cut north of Brewster. *P*, pale-green pyroxene showing striations due to inclusions; *H*, secondary hornblende; *Z*, zircon; light-gray ground mass *F*, feldspars, orthoclase and microperthite. Single nicol. Magnified 30 diameters.

This is an unusual combination to be found associated with such acidic feldspars as orthoclase and microperthite. Ordinarily, when olivine and pyroxene are the dominant ferro-magnesian minerals, the associated feldspar is at least as calcic as labradorite. The pyroxene is remarkable for its very pronounced striations. (Fig. 93.) These striations do not seem to be

the result of twinning, but rather of the manner in which inclusions have ranged themselves at a definite angle to one of the principal cleavages. Though the species of the pyroxene has not been positively determined, it is probably diallage. Along the edges of the crystals uralitization to hornblende has taken place. All of the hornblende in the rock is apparently of this secondary nature. The olivine has also been somewhat altered to serpentine and in places to secondary magnetite. Not much biotite is found, but it is of the brown variety and probably pyrogenetic. As an accessory mineral zircon is quite prominent, occurring in unworn euhedral crystals, often in slender rod-like forms. A little euhedral apatite has also been found. The magnetite presents some difficulties, for though a little seems to have normally crystallized out as one of the original minerals, the most of it is either a secondary development or one of the last products of crystallization from the magma.

The rock is unquestionably igneous. Its massive appearance, the character of its component minerals, and the manner in which these minerals have crystallized out, are all indicative of solidification from a molten magma. In its mineralogy it is more nearly a syenite than any of the other common rocks, but a rather basic variety. It is this rock which is most closely associated with the magnetite ore bodies of the Croton type, and it probably has an important bearing on their genesis, as will be brought out when these ore bodies are considered.

Relative Age and Distribution.—The data on which the determination of the relative age of the syenite is based are meager. It is no doubt younger than the sedimentary members, as it is found interlaminated with them in the same manner as is the granitic series. Its contacts with the latter, however, are so modified by shearing that it is impossible to apply the ordinary criteria, such as fragments of the one included in the magma of the other, contact phenomena, etc.

A specimen from this sheared zone when studied microscopically is seen to consist of the minerals of both kinds of rock, but quartz is absent. The minerals of the syenite are on the whole somewhat less crushed than those of the granitic gneiss.

To account for the depletion of quartz at the contact it is more reasonable to assume that the syenite was molten and intruded into the granite, its basic magma readily combining with the free quartz within the range of its influence. Had the reverse been the case, and the acidic rock had been intruded into the basic, it is likely that the fresh accessions of quartz from the molten interior would have replaced the small amount lost at the contact. Considerations like these, and the fact that the original massive texture has been better preserved in the syenite than in the granitic gneiss, are the reasons for ascribing a later age to it. The two rocks have many similarities and they are presumably consanguineous.

The largest and least altered occurrence of the syenite is just north of Brewster. It is well exposed in the cuts of both the Harlem and the New England railroads. It is here intrusive into granitic gneiss. South of this locality, near the Harlem depot, is a much smaller area. The rock is here more gneissoid and is intrusive into the sedimentaries. The old Simewog mine is located in this patch and it is not unlikely that the same extends over to the site of the old Townsend mine back of the Brewster House. About a mile further to the southwest a narrow band is exposed on which a prospect shaft has been sunk. The strike of this band if produced for a mile will just about hit the Theall end of the Croton mine, which is on a similar but thicker band. A mile further to the southwest an excavation for a dam site has uncovered an amphibolite dike, which although now made up chiefly of hornblende, appears to be an altered form of the syenite. In the extreme southwest corner of the district, beyond the county line, is another area of syenite, which was also the scene of some mining operations. All of these areas trend the same way, and as their appearance on the map suggests, may be the separated parts of one intrusive dike or upturned sill. A small isolated area having no apparent connection with the foregoing occurs north of Middle Branch reservoir, across the lake from the Tilly Foster mine. The rock exposed there is highly altered, with but traces of remaining pyroxene.

THE LIMESTONE (INWOOD).

That the gneiss of the Highlands is practically a continuous formation with the Fordham gneiss of the Harlem quadrangle, may be considered as fairly well established. Whether the schists of this region are identical with the Manhattan schists of Manhattan sland is still open to question, as the connecting links are fewer; but from their general petrographic character and geological situation it may be stated with a reasonable degree of certainty that they are. Between the gneiss and schists of the Harlem quadrangle lies a belt of crystalline, dolomitic limestone, locally known as the Inwood limestone. Its presence in this region would naturally be inferred, but no exposures have been found. It has, however, been discovered both north and south of this area, its position being always marked by low ground. This feature is due to its solubility in water containing carbonic acid, which, aside from direct solution, causes the rock to become friable and vulnerable to erosive agencies. Valleys in this region frequently owe their position to the ease with which this rock is eroded.

In the area under consideration we have a high ridge of gneiss on the northwest side of the Croton River and a ridge of schist on the southeast side. The river itself occupies a rather broad valley which has been filled with silt and glacial till far above bed rock. Taking into consideration this physiographic feature, combined with the geological situation of the valley, it seems highly probable that the valley marks the position of a considerable body of limestone. As having some corroborative significance, it should be stated that a few blocks of limestone were excavated in a deep canal dug across this valley. About a mile north of Croton Falls the valley begins to narrow down, due no doubt to an intrusion of diorite which cuts out the limestone, in part at least, and probably wholly.

INTERBEDDED LIMESTONES.

Though no exposures of any considerable body of limestone were discovered, yet a number of small beds were found inter-

bedded with the schists. The thickest of these beds did not exceed forty feet. It is to this nearness of the enclosing walls of durable schist that the smaller beds of limestone owe their preservation, where a larger bed would have been swept away by erosion. The best exposures occur about two miles due south of Brewster. The position of the other smaller exposures can best be seen on the map.

The limestone itself is a soft, friable, yellowish white rock, disintegrating readily under weathering influences. The actual exposure of solid rock is never more than a few feet in thickness, but the distinctive character of the residual soil makes it possible to form some estimate of the thickness of a bed. This soil has a brownish yellow color which contrasts rather strongly with the color of the prevailing till, it being often possible to recognize a small patch of limestone at a considerable distance by the color of its residual soil. A thin section of this rock under the microscope shows a mass of interlocking crystals of calcite through which are scattered grains of diopside. The latter is usually traversed by veinlets of serpentine following fractures and also around the periphery of the grains.

RELATIONS OF THE INTERBEDDED LIMESTONES TO THE MAIN BODY.

In the New York City region, where the boundary between the Inwood limestone and the Manhattan schist is more favorably exposed and where it has been thoroughly studied, it has been found that frequent alternations of schists and limestone occur in a transition zone between the two main bodies. If it is assumed that conditions in the Brewster region were similar, and the thickness and persistence of the limestone and schist formations warrant such an assumption, then it would follow that the main body of limestone ought to be somewhere near the outcrops of interbedded limestone. A glance at the map will show a low swampy tract of land lying just north of the principal exposures of interbedded limestones. Though this tract was necessarily mapped as schist, as that was the only rock exposed at its edges, it is not at all unlikely that the swamp marks the position of the main body of limestone.

THE SCHIST (MANHATTAN).

General Character.

This formation considered as a whole consists of a large body of micaceous schist, the aspect of which has been intimately affected by numerous igneous intrusions and injections of granitic and basic material. The intrusives are so numerous in places as to greatly predominate over the schist. Banding due to these intrusives and to some extent to original stratification is very marked and in many places, especially where the intrusives predominate, it may be very difficult to differentiate the schist from the gneiss. Areal study, however, will reveal a frequent recurrence of a micaceous phase in the schist, which is absent in the gneiss. The schist weathers more readily than the gneiss. Its color in any locality depends npon the prominence of some particular intrusive, but it is on the whole darker than the gneiss. Grayish brown is perhaps the most common color.

The more micaceous varieties are made up of green biotite interlaminated with quartz and orthoclase. Garnet often appears in conspicuous crystals. Sillimanite may also be visible to the naked eye. Gradations from this variety to a black amphibolite on the one hand and to a white pegmatite on the other, constitute the range. Folding and contortion have been intense. The strike is generally northeast and southwest as with the gneiss, but in the southeast corner of the area the strike changes to east and west. The dip is prevailingly vertical, although sometimes very flat.

Microscopic Character.

A thin section from one of the micaceous streaks will show about equal proportions of quartz and green biotite, some orthoclase and plagioclase, as essential minerals, and garnet, magnetite and sillimanite as accessory minerals. (Fig. 94.) The quartz occurs in rudely polygonal grains arranged in aggregates lying parallel to the flakes of biotite. It seems in this case to be a product of crystallization from solution rather than a cementation of quartz sand. The grains are comparatively

clear, rutile needles being the most prominent inclusions. These needles are about equally distributed among the different grains. A single needle will sometimes be found piercing two adjacent but differently oriented grains, a phenomenon which would hardly happen with two adjacent clastic grains. Orthoclase sometimes shows the microcline modification. The plagioclase is always acidic, usually between albite and oligoclase. Garnet is not regularly distributed, but is much more abundant locally. The same can be said of sillimanite. This mineral occurs in aggregates of

FIG. 94. Schist from area south of Brewster. Light gray *Q*, quartz; dark gray and black *B*, pleochroic biotite; *S*, sillimanite needles; *G*, garnet; *O*, orthoclase. Single nicol. Magnified 30 diameters.

brilliantly birefringent, needle-like crystals which are very characteristic. Magnetite seems to be secondary, though it is sometimes included in garnet.

If a thin section of the light-colored feldspathic phase of the schist formation is studied under the microscope the following differences are noted. A great increase in the percentage of orthoclase and microcline, which may now constitute one half

of the whole. Plagioclase, chiefly albite, has also increased. Quartz has diminished and biotite, magnetite, garnet and sillimanite have entirely disappeared. A considerable percentage of muscovite is now present, and this gives to the rock its imperfectly schistose character. The minerals are all comparatively bright and clear, free from inclusions except along fracture lines. The rock is undoubtedly made up chiefly of igneous material and may be taken as an example of the acidic extreme of the intrusives which permeate the schists.

A thin section from one of the dark basic bands will show a still more notable percentage of quartz, but orthoclase has greatly diminished and albite increased. Green biotite and hornblende togeher make up about one fourth of the whole. Apparently the hornblende has been derived from pyroxene, of which there still remains a little. The quartz and feldspars are rather uniformly mixed, quartz being sometimes included in the feldspar. The biotite shows the ragged and bent structure which is characteristic of its occurrence in schist. Biotite and hornblende carry a notable percentage of magnetite as inclusions. Nothing very positive can be deduced from this slide, but the presence of some residual pyroxene, with the probability of a much greater amount originally, are indicative of a basic igneous rock. On the other hand, the disturbed relationship of quartz and feldspar suggests a sedimentary source or crystallization from solution.

Distribution.

The schists take up all of the area lying southeast of the Croton River Valley, with the exception of a part occupied by a dioritic intrusion which extends northeastward about two miles from Croton Falls. This intrusion may be considered a part of the schist formation, as it is closely involved with the distinctively schistose members, and has participated in the same deformative movements, and has been subjected to the same dynamic action. It is, however, a body of such extent, and is so clearly an igneous intrusion that it was considered of enough importance to map separately.

THE DIORITIC INTRUSION.

General Character.

In its least altered exposures this intrusive consists of a rock which mineralogically approaches a diorite, but which exhibits several textural phases. Its dominant phase is porphyritic, when it occurs as a rock having a dark or nearly black, fine-grained groundmass through which are sprinkled lath-shaped, white spots resembling feldspar phenocrysts. The undisturbed porphyritic texture is, however, visible in only a few places, and then it is limited to but a few feet in width. It grades rapidly into sheared and streaked rocks in which the phenocrysts range themselves longitudinally, finally breaking up and merging into each other. In the sheared zone a network of quartz and feldspar veins and veinlets serve to bind together the crushed strips. These veins are either pegmatitic injections or deposits from infiltrating solutions.

At the boundary of the porphyry with the schist, when not modified too much by secondary injections, the phenocrysts exhibit a decidedly parallel arrangement, coinciding with the direction of the schistosity. The phenocrysts are much smaller near such contacts, being about two millimeters in length, whereas near the central parts they attain a centimeter. Many of the small basic bands interlaminated with the schists are, no doubt, minor offshoots from this same body, but which have lost much of their original character through admixture with enclosing rocks. The diorite is somewhat more resistant to weathering than the schist, the contact between the two being often marked by cliffs of the former.

It is probable that the intrusion as a whole is the result of a number of closely consanguineous, but distinct irruptions. Of these the porphyritic phase was the first and by far the greatest. After cooling it was cut by dikes, from five to ten feet in thickness, having a similar mineralogical composition, but finely crystalline in texture. Dikes of a coarse-grained hornblendite have also cut the porphyry, sometimes extending beyond its limits into

the schist. It is mineralogically very much like the porphyry minus the feldspars.

Microscopic Character.

The principal minerals of the porphyritic phase of the diorite are hornblende, green biotite and labradorite. Orthoclase and quartz also occur in considerable quantities, but it is doubtful if they are primary constituents. Magnetite, pyrite, titanite, leucoxene and apatite occur as rather abundant accessory minerals. The phenocrysts, which are so plainly apparent to the naked eye, are followed with difficulty under the microscope. Instead of a single crystal of feldspar, they consist of aggregates of differently oriented grains of feldspar, all labradorite, roughly limited by the boundary lines of what was probably a single crystal originally. Internal crushing seems to be the most reasonable explanation of this peculiar structure. It is not likely that the original crystal had been changed chemically and had suffered recrystallization for that reason, for all of the secondary influences, to which the rock has been subjected, were acidic in their nature, whereas the labradorite of the aggregates is the most basic feldspar yet found. Hornblende, which makes up one half of the total amount of minerals, occurs in small grains, in some respects resembling uralite, but no trace of residual pyroxene was found. Most of the hornblende grains were full of holes which had been filled by quartz, and it appears that this is the only manner in which quartz occurs in this phase of rock. This statement, of course, does not apply to the sheared zones which are traversed by veinlets of quartz and orthoclase. Magnetite occurs as poikilitic inclusions in hornblende, usually surrounded by a film of leucoxene. Its distribution in a hornblende grain is affected by the cleavage of that mineral. Leucozene is not always associated with magnetite, much of it occurring in lumps by itself, but included in the hornblende. From the way in which the proportions of these two minerals vary it would seem that we have a titaniferous magnetite or ilmenite to begin with; solution removes the iron, leaving a residue of titanic acid which reacts on other minerals present to form the indefinite mineral leucoxene. This

process may continue until all the iron is removed, and only the leucoxene remains. Apatite, when present, occurs in euhedral grains, and is evidently a primary mineral.

The cryptocrystalline phase of diorite found in the dikes is made up of practically the same minerals in the same proportions, with the addition of a small amount of light-colored pyroxene. It is not unlikely that pyroxene was originally present in the diorite porphyry also, but as that is older than the dikes it may have had all of its pyroxene altered to uralite, while the change

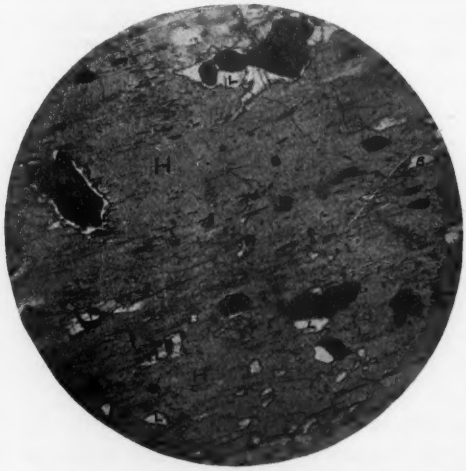

FIG. 95. Hornblendite phase of diorite intrusion from railroad cut south of Croton Falls. *H*, single hornblende individual, with other minerals as poikilitic inclusions; *M*, magnetite; *P*, pyrrhotite; *L*, leucoxene incrustations, *B*, biotite. Single nicol. Magnified 30 diameters.

in the younger body has not been complete. The magnetite of the dikes shows a much smaller amount of encrusting leucoxene, which may also be indicative of lesser alteration.

In the dikes of hornblendite the hornblende amounts to about three fourths of the whole. The other essential mineral is biotite. Magnetite, pyrite, titanite and apatite are accessory min-

erals. Chlorite and leucoxene occur as alteration products. The crystals of hornblende, though anhedral, are exceptionally large and have a well developed cleavage parallel to the elongation. This mineral acts as a host for practically all of the other minerals present, even biotite being included by it. Magnetite with encrusting leucoxene is a very abundant inclusion, especially along cleavage planes. (Fig. 95.) Apatite and titanite occur as euhedral crystals and were probably the first minerals to crystallize. Feldspar and quartz are entirely absent. It may be said in this connection, that although all phases of the diorite are rich in magnetite, none of the known ore-bodies seem to have any traceable relationship with the intrusion.

Distribution and Age.

The dioritic intrusion covers an area on the map extending from the southwest corner about three miles in a northeasterly direction. At Croton Falls it attains its greatest width, about three fourths of a mile, and it is here that it exhibits its most massive and coarse-grained phases. Going north along its strike the width becomes much less. It is found cutting the schist and also interbedding with it. At Croton Falls its outcrops closely approach those of the gneiss, although the direct contact has not been observed.

From the data at hand it would appear that the intrusion took place after the sediments of limestone and shales had been laid down, but before folding or metamorphism. Its form was probably that of a laccolith, with its central neck cutting the limestone and shales at Croton Falls, and with sills extending northerly into the shales. The principal dynamic movements which folded the sediments and affected their metamorphism from limestones and shales to crystalline dolomites and schists, did not occur until after the intrusion, for the diorite shows the same intricate deformation, has the same general strike and has its minerals arranged parallel to the general direction of the schistosity.

PEGMATITE DIKES.

General Character.

Cutting the schist and diorite is a series of white pegmatite dikes, varying in thickness from a few inches to twenty-five feet and even more. They are irregularly distributed throughout the schist area, often forming large and prominent outcrops. This is due to the extremely resistent quality of the rock which withstands weathering better than any other rock exposed here. In strike and dip it is variable, not conforming with the prevailing strike and dip of the enclosing rocks, though apparently not entirely independent of them. It is a white rock, having coarse pegmatitic texture showing quartz and feldspar to the naked eye.

Microscopic Character.

Under the microscope the rock consists of quartz, microcline, orthoclase and albite in nearly equal proportions. They form a mass of coarse, interlocking anhedrons with no apparent sequence of crystallization. Quartz is often included in feldspar. Granophyric intergrowth of orthoclase and quartz is also very common. Occasionally isolated little nests of tourmaline crystals may be found. Crushing is evident by wavy extinction and strings of inclusions marking fracture lines, but on the whole the minerals present a rather fresh appearance.

Relative Age.

The pegmatite dikes are plainly later than the schist and diorite, for they cut across these formations regardless of the existing foliation. Some folding has, however, taken place since their intrusion, as is plainly evident by the contorted outcrops of the dikes and corroborated by the crushed condition of the minerals. It would appear, then, that the pegmatite intrusions happened in the interim of folding, following upon the movement which metamorphosed the sediments, but prior to the final period of folding and upheaval to which the region has been subjected.

GLACIAL DRIFT.

A deposit of glacial drift covers this area like a mantle, leaving but few exposures of the underlying formations. This, of course, adds enormously to the difficulty of correctly mapping a complicated region. A partial compensation is afforded in the clean fresh surfaces of such exposures as do occur. The constitution of the drift of this locality does not indicate very distant transportation. It has on the whole a greater proportion of fine material, which is to be expected of the detritus of such rocks as the schist and the limestone. Transported boulders are white pegmatite, granite and granite gneiss and some quartzite. The thickness is, of course, extremely variable. A thickness of about fifty feet was removed at the dam site, but this is not an especially significant location, and much greater thicknesses no doubt exist. Most of the glacial grooves have been obliterated, but a few that were observed indicate a nearly north and south direction of movement. The glacial deposits were not mapped, as they are so nearly universal over this area that to have done so would have obscured the significance of the other formations. However, as most of the actual hard rock exposures have been indicated on the map, the areal distribution of the drift may be inferred.

ECONOMIC GEOLOGY.

DESCRIPTIONS OF THE MINES.

The Tilly Foster Mine.

Location and History.—The Tilly Foster mine is located in the northern part of the area covered by this investigation, on a point of land jutting out into the lake at the north end of Middle Branch reservoir. At the time that iron mining was active in this region it had a value and importance greater than any other in Putnam County, and from the excellence of its ore and the unusual minerals found, it was celebrated beyond all others. The first record we have of any mining is in 1810, when a small quantity of iron was manufactured from ore outcropping

on the surface. From that time until 1853 scarcely any attempt was made to develop its resources, though Mather mentions it in his geological report of 1839. In 1868 the monthly production was about 1,000 tons. In 1879 it had risen to 7,000 tons, but again declined to 2,000 in 1885. As greater depths were reached it became increasingly difficult to mine the ore, and expensive stripping operations had to be resorted to. The mine gradually declined in importance and was finally abandoned in 1897 after a number of disastrous accidents.

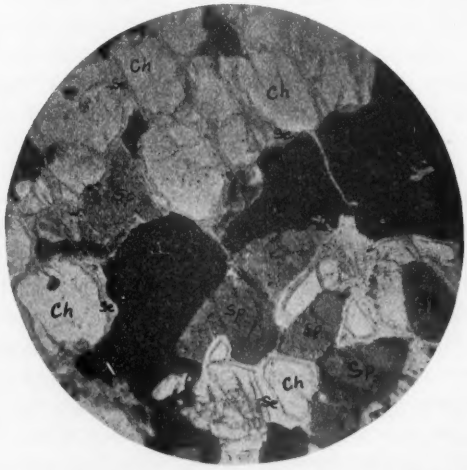

FIG. 96. Lean ore from Tilly Foster mine. *Ch*, chondrodite; *Sp*, spinel; *Se*, serpentine; *M*, magnetite. Single nicol. Magnified 30 diameters.

General Character of the Ore-body.—The ore-body originally was in the form of a huge lens about 500 feet long, 160 feet wide at its thickest part and worked to a depth of over 600 feet. The enclosing walls were banded gneiss, of the kind which has been classed with the sedimentary group. The longer axis of the ore-body conformed with the strike of the gneiss, about N. 10° E. Its dip was about 70° E. Its greatest breadth was partly due to a fault which had the effect of doubling the ore-

body for a portion of its length. The ore itself is a finely crystalline magnetite through which are scattered yellow and red grains of the rare mineral chondrodite, a fluosilicate of magnesium. A soapy green mineral, probably serpentine, also occurs with the ore, as a coating of the fragments into which it breaks with great facility, especially where chondrodite is abundant.

Microscopic Character of the Ore and Gangue.—A thin section of ore examined under the microscope shows only four minerals: magnetite, chondrodite, spinel and serpentine. (Fig. 96.) The chondrodite is the most abundant of the gangue minerals. It occurs in rounded pleochroic grains largely altered to serpentine. This alteration is most pronounced at the periphery of the grains, but also takes place along irregular lines of fracture which traverse the grains. The soapy green mineral, coating fragments of ore, can no doubt be referred to this cause. Spinel occurs in euhedral crystals and seems to have been the first mineral to have crystallized, the apparent order being spinel, chondrodite, magnetite and serpentine. Magnetite molds itself around grains of spinel and chondrodite. Part of it also occurs as inclusions in these two minerals, sometimes in microscopic octahedra, but even then it has probably formed later than its host, as it is found in strings and bunches, indicating deposition along lines of weakness in the host. Spinel has also suffered partial alteration to serpentine. It will be noticed that all of the gangue minerals are magnesic. The analyses given below, from Putnam's[1] and Wendt's[2] papers show the uncommonly high percentages of magnesia for which this ore is noted.

No mention is made in any of the old descriptions of the Tilly Foster mine of the manner in which the chondrodrite-bearing crystalline limestone is related to the ore-body. This limestone is common on the dump, however, and must have been closely associated with the ore. It probably has a direct bearing on the problem of the genesis of the ore. Under the microscope it consists of about one half calcite, one fourth chondrodrite, the balance being made up of green pyroxene, spinel, ripidolite and

[1] Tenth Census of U. S., Vol. 15, p. 593.
[2] *Transactions A. I. M. E.*, Vol. 13, p. 481.

magnetite. The calcite forms a body of interlocking crystals in which the rounded grains of chondrodrite are set. The green pyroxene is peculiar in being pleochroic, though not orthorhombic. It seems to be an earlier crystallization than chondrodite. Another uncommon mineral is the light green mica, ripidolite,

	Putnam.		Wendt.
	300 ft. level.	110 ft. level.	Shipments.
SiO_2	12.18	10.81	12.67
FeO	21.99	23.36	22.67
Fe_2O_3	44.75	44.30	48.24
Al_2O_3	.79	1.11	
MnO	.10	.04	.17
CaO	3.10	1.19	
MgO	11.72	16.33	13.20
FeS_2	1.031	1.01	
P_2O_5	0.034	0.015	.019
H_2O	4.08	1.c5	.05
CO_2	.40	.28	
C		.01	
SO_3		.05	
K_2O		.12	
Na_2O		.22	
	100.175	99.895	97.019

probably an alteration product from pyroxene. Spinel occurs in crystals much clouded by magnetite dust. Magnetite also occurs in a few larger grains, but in insignificant quantity.

If some of the thin-banded gneissic wall rock of the ore-body is studied under the microscope it is shown to be made up of about two thirds quartz and orthoclase. A small quantity of acid plagioclase also exists. Green biotite is the only ferromagnesian mineral and to it is due the banded structure. The quartz and feldspar occur as a fine-grained aggregate, often clouded by a smirch of included matter. Quartz is frequently included in the feldspar. As accessory minerals apatite, titanite and calcite have been found, but not a trace of magnetite. It will be noticed that the petrographic character of this rock corresponds closely with that of other gneisses already described, in which a sedimentary origin could be fairly well substantiated, and it is probable that it was also originally a sediment.

Views of Early Observers.—Shaler[1] noticed limestones about 500 yards north of the mine, but thought that they may come nearer than that. He regarded the ore-body as a bedded deposit which had been pinched into local agglomerations of ore.

H. S. Monroe[2] regarded it as a stratified deposit underlain by beds of sandrocks, shales, etc. After deposition of the ore originally as brown hematite, with perhaps carbonate of iron, it was covered by a similar series as below. He considered that by folding and metamorphic action the beds had been tilted and metamorphosed and the different minerals had been secreted.

Dana[3] thought that the ore was originally a marsh deposit. He considered that most of the ore beds in southeastern New York and in New Jersey were sedimentary, because of their general parallelism to the surrounding rocks. While this feature was not so evident at the Tilly Foster, he thought that the similarity of the rock and the similarity of the ore pointed to a similar origin.

A. F. Wendt[4] remarked upon the mineralogical similarity of the Tilly Foster ore to the Mahopac ore. At the Mahopac mine, however, four beds of ore from ten to fifty feet wide alternate with beds of gneiss. He considered the Croton ore-body a different type from the Tilly Foster and Mahopac, but did not advance any theories as to the origin.

F. S. Ruttman[5] in a paper which gives a very complete description of the local geology, considered the Tilly Foster ore-body to be without doubt of sedimentary origin. The identity of the strata of gneiss which forms the foot-wall, with that of the hanging-wall is advanced as proof of this. He speaks of ore sediment carried in mechanical suspension by streams, and deposited in a basin or depression, and covered by layer on layer of rock sediment, until by accumulated pressure and heat the rock sediment is changed to gneiss, and the ore through successive

[1] W. S. Pelletreau, History of Putnam County, New York.
[2] *Idem.*
[3] *Idem.*
[4] *Trans. A. I. M. E.*, Vol. 13, p. 478.
[5] *Trans. A. I. M. E.*, Vol. 15, p. 79.

stages to magnetite. He even considers the present lenticular shape of the ore-body to be due to the original contour of the basin, but which in folding has been overturned, as the greatest bulge of the ore-body is now on the hanging-wall side. He refers the Croton ore-body to the same geological horizon as the Tilly Foster, and thinks they were deposited as sediments under the same general conditions.

The Croton Mines.

Location and History.—The Croton mine comprises the combined workings of the Theall and the McCollum mines, located on opposite ends of the same ore-body. The Theall mine lies about half way between Brewster and Croton Falls and a half mile west of the Harlem River Railroad. The McCollum mine lies a half mile further to the southwest.

The ore-body has been known for a long time. Mather describes it in his report of 1843, and Dr. Beck in 1856. Some ore had then been taken out at the Theall end. It was worked in a desultory fashion after that until about 1880, when work was also begun at the McCollum end. In 1883 the mine was closed down to be again reopened in 1889. After a few years, however, the ore became so pyritous and low grade that the mine was finally abandoned and has not since been reopened.

General Character.—The ore-bearing ground varies in width from 50 to 100 feet, but the full width is never minable, only the richer streaks which are separated by varying thicknesses of low grade rock. The length of the ore-body as shown by its two openings is 2,500 feet, but it probably extends further each way in leaner streaks. It strikes about N. 30 E. and dips steeply to the southeast. The walls are usually not well defined, apparently being of the same material as the ore, but less highly impregnated with magnetite. This wall rock has the characteristics of the syenitic gneiss which always carries some magnetite. The lean ore also bears a striking megascopic resemblance to the syenite when heavily impregnated with magnetite. Next to the immediate country rock of the ore, the banded gneisses of the

sedimentary group appear rather heavily injected from the granitic mass to the west.

Microscopic Character.—Under the microscope, specimens of ore sufficiently lean to show the associated minerals consisted of orthoclase, albite-oligoclase, quartz, hornblende, biotite, pale green pyroxene, apatite and pyrrhotite, with magnetite in all proportions depending on the grade of ore. (Fig. 97.) Of these

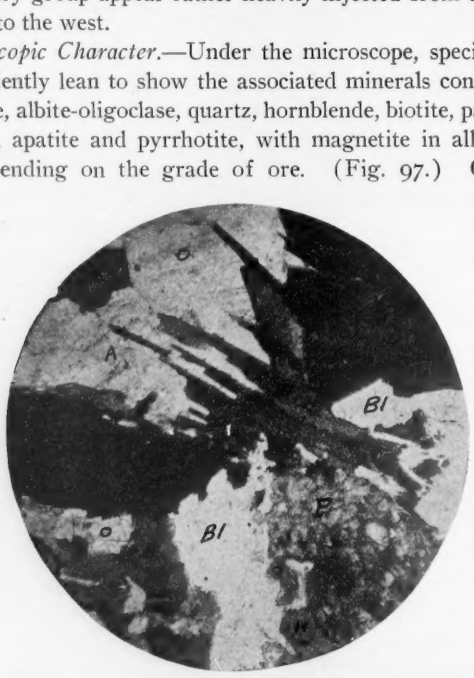

FIG. 97. Lean ore from Croton mine. *M*, magnetite; *O*, orthoclase; *A*, albite; *B*, biotite, pleochroic shades; *P*, pyroxene; *H*, hornblende; *Bl*, blank in section. Single nicol. Magnified 30 diameters.

quartz was sometimes absent, and was probably secondary. The orthoclase and pyroxene were the most persistent minerals, occurring in all the slides examined. The plagioclase was always of the sodic species. Hornblende was largely dependent on the pyroxene, from which most of it seemed to have been derived. Biotite was a subordinate mineral. Apatite and pyrrhotite and perhaps some pyrite were sometimes in relatively large quantities. The apatite often occurred in large grains and was generally euhedral. This mineral when found in the ore, or in the syenite, was anomalously biaxial in the great majority

of cases. Pyrite and pyrrhotite were closely connected with the magnetite, generally being surrounded by it. Occasionally a few little euhedral zircons were found.

It is apparent from this description that petrographically the lean ore is very much like the syenite. It has the same minerals in much the same proportions, with the exception of olivine. This mineral was, however, only found in the most massive and least altered portions of the syenite. With regard to the order of crystallization, the only fact that was brought out clearly in the microscopic examination was that magnetite was later than any other mineral, with the possible exception of quartz. Its manner of molding itself on feldspars and pyroxene, and reaching into fractures and crevices clearly proved that.

The magnetite seldom occurred pure in bodies of any considerable size, and in order to get a commercial grade of ore all the lean stuff had to be sorted out. Such close sorting was not necessary at the Tilly Foster, even if the ore ran low, as the associated minerals were self-fluxing. The Croton mine had to contend with the additional difficulty of a high sulphur percentage. According to Hoffman[1] one-third of the crude ore was heavily impregnated with pyrites. Pyrrhotite also occurred in irregular lumps and in layers from one to two feet in thickness. The following complete analysis from Wendt's paper[2] is of ore shipped in 1883. The partial analyses are from Putnam.[3] They all show an ore so low in iron and high in phosphorus, as to be of little value at the present time.

Wendt	
Croton Ore Shipments.	
Fe_2O_3	47.17
FeO	21.52
MnO	.51
Al_2O_3	8.55
CaO	2.10
SiO_2	18.93
P	.21
S	.52

Putnam.		
	1st Class.	2d Class.
Fe	51.48	43.22
P	0.247	0.255
TiO_2	Present	

[1] *Trans. A. I. M. E.*, Vol. 21, p. 513.
[2] *Trans. A. I. M. E.*, Vol. 13, p. 486.
[3] Tenth Census of U. S., Vol. 15, p. 101.

The Brewster Mines.

Location and History.—These two old mines lie in the city of Brewster, one just back of the Brewster House and the other at the foot of the hill west of the Harlem River depot. They were opened about 1810, but abandoned in 1820 after some 50,000 tons had been extracted. Some ore was again taken out in 1845 and off and on until 1880, since which time they have been abandoned.

Owing to the lack of time, it was not possible to study these mines closely, but the ore seemed to be of the same nature as the Croton. According to Mather[1] the vein was traced 1½ miles to the south-southwest and apparently continued even further. Its connection with the Croton is thus suggested. He states that the ore is from eight to twenty feet wide, lying between walls of granitic gneiss and hornblendic gneiss. The hornblendic gneiss is no doubt a gneissoid form of the syenite, which in this case seems to show the greatest enrichment near the contact with the granitic gneiss.

PROSPECTS.

Half way between the Brewster and the Croton mines a shaft was sunk to a depth of thirty or forty feet on a narrow band of ore, which was interbedded with the members of the sedimentary group. Some of the ore on the dump was examined under the microscope and proved to be of the same syenitic character as the Croton ore, but very low grade. The minerals were orthoclase, acid plagioclase, green pyroxene, hornblende, magnetite and apatite. A little leucoxene was also found. The position and strike of this band are such that it could easily be an extension of either the Brewster or Croton ore bodies.

Another old working lies a half mile west of Croton Falls, south of the county line. The mine itself just falls off the map, but its position is indicated by the syenite area in which it lies, and which extends into the map at the southwest corner. A large magnetic concentrating mill had been built to treat the ore from

[1] New York Geological Reports, 1839, p. 110.

this mine, but the extent of actual mining operations was an open pit from which a few hundred tons had been extracted. The ore is a syenite like at the other mines just described and presents no new features. Zircon was rather more abundant than usual. This mineral always occurs in well-formed euhedral crystals, not rounded or waterworn like a detrital grain. The syenite of this locality is not heavily impregnated with magnetite, being of lower grade than at the Croton or Brewster mines. The rocks of the sedimentary group lie to the south and east, but the granitic gneiss approaches closely to the north of it. The strike is N. E. and S. W., and here again a southwest extension of the Croton ore-body on its strike, would not miss this body very far.

Views of Early Observers on the Croton Type of Ore-Body.—Professor Mather, in his report for 1839, felt himself constrained to consider ore-bodies of this type as veins. He says, "Their course is parallel to the line of bearing of the strata, and they lie parallel to layers of rock, but by close examination it is found that in several instances, after continuing with this parallelism for a certain distance, the ore crosses a stratum of rock and then resumes its parallelism, then crosses obliquely another, and so on."

Shaler[1] examined the Croton ore-body and considered it a bed, not a vein. He did not state in what manner such a bed might be formed, but as he thought it possessed the element of certainty to the same degree as a coal bed, he presumably had a sedimentary origin in mind. On this basis he figured the Croton ore-body to contain 50,000,000 tons, mining to a depth of 1,500 feet, of which three-fourths was minable ore. Needless to say, later developments did not bear out his optimistic forecast.

Dana, as has already been stated, considered all of the magnetite deposits in this part of the state as metamorphosed marsh deposits, but he had especial reference to bodies which, like the Croton, were markedly parallel to the foliation of the gneisses.

In general it may be said that geologists and mining engineers familiar with these ore-bodies, at the time when they were being

[1] *Trans. A. I. M. E.*, Vol. 20, p. 603.

worked, were inclined to attribute a sedimentary origin to them. Since that time, however, the importance of the igneous agencies in the formation of all ore deposits has become more generally recognized, and it is not unlikely that could these magnetite deposits be thoroughly studied in the light of the newer conceptions that their origin could in many cases be more adequately explained.

DISCUSSION.

There can be but little doubt that the Tilly Foster and the Croton ore-bodies are two distinct types of magnetite deposits, differing not only in form and in mineralogical composition, but also in mode of formation. The Croton type is by far the most common. Most of the magnetite bodies in the Highlands can be referred to this type. The Tilly Foster on the other hand is nearly unique. The only similar ore-body in the United States, so far as known, is at the Mahopac mine, which is only about eight miles west of the Tilly Foster. Sjögren[1] in a recent paper mentions a similar deposit at Nordmarken, Sweden, where the same peculiar combination of minerals is found with the magnetite.

It is this gangue of uncommon minerals which is the most strikingly distinct feature of the Tilly Foster ore-body. Chondrodite, the principal gangue mineral, is according to Iddings,[2] developed chiefly in metamorphosed limestones, altered by contact with igneous rocks, such as inclusions in Vesuvian lava, and in zones of contact metamorphism. The next most prominent gangue mineral, green spinel, is frequently developed in dolomite, by contact metamorphism, according to the same authority. Serpentine, which is also common, is an alteration product, and has no special genetic significance. Fluorite has been found associated with the ore, and although it is not one of the common gangue minerals, its presence in conjunction with that of the fluosilicate, chondrodite, is expressive of contact metamorphic action. This mineral is frequently a product of the vapors or

[1] *Trans. A. I. M. E.*, Vol. 38, p. 796.
[2] "Rock Minerals," Iddings, p. 373.

gaseous exhalations given off by a cooling igneous mass in the last stages of crystallization, aptly termed "expiring vulcanism" by Professor Kemp.

The ore is not structurally different from the chondrodite-bearing limestone found on the dump. Even the grains of chondrodite and spinel are distributed throughout the mass in the same manner, but in the ore we have magnetite taking the place of calcite and pyroxene. Crystalline interbedded limestones have been found less than a half mile from the Tilly Foster in the line of strike of the gneiss, carrying the same associated minerals with the exception of the contact metamorphic products, chondrodite and spinel. The gneisses adjacent to the ore-body are of sedimentary origin as nearly as can be determined.

It seems probable in the light of these facts that the chondrodite-bearing limestone found associated with the ore is what remains of an original body of interbedded limestone. This limestone was subjected to contact metamorphic action by the intrusion of an igneous magma, which was probably either granitic or syenitic, as both of these rocks outcrop in the neighborhood. This resulted in the formation of such minerals as chondrodite, spinel and fluorite. Whether magnetite was formed simultaneously with these minerals as a direct product of contact metamorphism is not apparent, but from the way in which it molds itself around these minerals it was probably formed later, after the igneous mass had cooled sufficiently to give off liquid solutions instead of vapors. If these solutions were iron-bearing it would be easy to account for the formation of the magnetite by metasomatic replacement of calcite and dolomite. The removal of the calcium could also be more readily effected by liquids than by vapors.

It may be argued that replacement of the calcite by iron-bearing surface waters would likewise explain the introduction of the iron, but the fact that minerals like chondrodite and spinel retained their identity during the period of transformation would indicate that the conditions under which they were formed had not greatly changed.

The intimate association of these two minerals with the mag-

netite, precludes the possibility of a sedimentary origin. Segregation from an igneous magma on the other hand would adequately explain the presence of spinel, but not of chondrodite. The action of escaping gases and liquids from an igneous magma, upon a body of limestone, may be productive of just such minerals as are found with the ore, and on the whole this seems to be the most adequate explanation. In speaking of similar deposits in Sweden, Sjögren accounts for them by metasomatic replacement of limestones by iron-bearing solutions, and emphasizes their magmatic character.

The form of the Tilly Foster ore-body is no longer that of a bed, but in view of the extreme deformation that the whole gneiss series has undergone this cannot be considered an important objection. At the Mahopac mine, the only other place in the United States where a similar ore is found, it occurs in four parallel beds separated by beds of gneiss, thus more nearly approaching the structure of an interbedded limestone series.

In the case of the Croton ore-body more can be said in favor of the idea of sedimentary origin. The shape of the ore-body in the first place is strongly suggestive of a bed. At the Croton mine this bed has been proved to be at least a half mile long, and there are good grounds for believing that the Brewster mines at the north end, and the old mine west of Croton Falls at the south end, are really on this same ore-body, which would give it a length of nearly five miles. The banded gneisses with which this bed is so markedly parallel are sedimentary, in part at least. Under the microscope it appears that magnetite was the last mineral to form, which would not be inconsistent with a sedimentary origin, either, as a metamorphosed bog deposit, or an agglomeration of magnetite sand.

When the petrographic character of the ore-bearing rock itself is analyzed, however, it is difficult to conceive of it as an original sedimentary rock. The presence of such minerals as green prroxene and euhedral zircon; the development of the feldspars in large individuals, except in places subjected to later crushing; the same apparent order of crystallization as the minerals of an igneous rock, with the one exception of magnetite; are all features

which lead one to infer an igneous rock. The fact that magnetite instead of being one of the first minerals to crystallize out, as it generally is in igneous rocks, is on the contrary the last to form in the ore, is the greatest objection to considering it as a basic segregation from the syenite magma. Our knowledge on this subject is as yet very incomplete, however, and it is not unlikely that under certain conditions magnetite may be the last mineral to separate from the magma, as it evidently is in the rock koswite from the Ural Mountains.

The most serious impurity in the ore is sulphur, occurring chiefly in the form of pyrrhotite, a mineral which is almost always pyrogenetic. Titanium has also been found in a few thin sections of ore, as leucoxene encrusting grains of magnetite, and Putnam reports it as present in some analyses of Croton ore. Though present in all quantities only, not nearly enough to constitute a titaniferous magnetite, nevertheless it shows that the ore is analogous to the titaniferous magnetite ores, which are now generally conceded to be the result of segregation from a basic igneous magma. Moreover, though the ore-body structurally resembles a bed, the distribution of the magnetite throughout that bed is not nearly as uniform as one would expect if it were laid down as a sediment contemporaneously with the inclosing rocks.

If, on the other hand, we assume that a syenitic magma was intruded into the sedimentary series in the form of a sill, the general parallel structure would be retained, for in all subsequent deformative movements the sill would behave just like a bed. The great variations in thickness of the ore-bearing ground could be more easily explained on the basis of a sill, as could also the occasional crossing of strata, which was first observed by Mather. The ore-bodies themselves would then have to be interpreted as portions of the main body of the sill, in which the syenite magma was locally so enriched by segregation of magnetite as to become an ore. On this hypothesis it is believed a reasonable explanation would be afforded for the apparent location of the ore-bodies on a definite stratigraphical unit; their restriction to a certain kind of rock; and their irregular distribution throughout that rock.

As opposed to segregation, there is a possibility that ferriferous solutions may have introduced magnetite either by replacement or simple filling of open spaces. The syenite, however, lacks easily replaceable minerals like calcite, while other minerals like olivine or pyroxene would be likely to leave pseudomorphous casts, none of which were found. One point in favor of simple filling is the anomalously biaxial character of most of the apatite in the ore-bearing rock. According to Iddings[1] large apatite crystals that have grown in cavities may have this optical property. The weight of evidence, however, seems to be in favor of segregation from an igneous magma.

It is noteworthy that syenite, especially when rich in soda, as found with the Croton type of ore-bodies, is a common wall rock of magnetite deposits occurring in widely separated regions. The augite syenites with which the Adirondack magnetites are chiefly associated according to J. F. Kemp[2] have as chief minerals microperthitic orthoclase and green augite, very much like some phases of the Croton syenite. In his paper on the Swedish iron-ores Hj. Sjögren[3] remarks upon the frequency of rocks rich in soda among the magnetite bodies in the Archean gneisses. The great Kirunavaara deposit in Lapland is also, according to him, a segregation from a soda-syenite porphyry.

ECONOMIC CONSIDERATIONS.

There is little doubt that all magnetite ore-bodies in this region which are actually exposed have already been found. So much of the area is drift-covered, however, of which but a small part has been prospected by magnetic methods, that there is still a possibility of commercial deposits existing underneath the concealing mantle. Under present market conditions ore-bodies of the Croton type would offer but little incentive for exploring operations. The ores are of such low grade, and carry such high percentages of sulphur and phosphorus, that it does not pay to mine them at present, even where they are well exposed and partly

[1] "Rock Minerals," p. 477.
[2] New York State Museum, Bull. 119, p. 64.
[3] *Trans. A. I. M. E.*, Vol. 38, p. 772.

developed. On the other hand, the ores of the Tilly Foster type of deposits are so tractable, and have such small percentages of deleterious elements, that even if low grade, deposits of this kind could not fail to have considerable value. A magnetic survey of the whole area in which such deposits may occur is of course impracticable. However, if the conclusions reached, regarding the genesis of these ore-bodies and their relations to the surrounding rocks are correct, it should be possible to select relatively small areas, on the basis of their geology, to which more detailed examination could be confined.

The Tilly Foster ore-body is thought to be a replacement of an interbedded limestone in the gneiss series, due to the influence of a nearby igneous intrusion. Clearly, then, the first step in the search for a new ore-body of that type would be to look for exposures of interbedded limestones in the gneiss area, working radially outward from the Tilly Foster and Mahopac mines. These are fairly common, but often so altered as to be scarcely recognizable. They should be carefully examined for contact minerals, especially those of the chondrodite group. The latter are not very common, but have been found in a number of localities in the Highlands, and no doubt careful, specific search would reveal their presence in many of the interbedded limestones. From the strike and dip of these limestones and the enclosing gneisses it may be possible to approximate their position under the drift, and to decide upon relatively small portions of the drift-covered area as being of enough promise to justify a magnetic survey.

The same mode of procedure may be followed in prospecting for deposits of the Croton type, except that the key rock in this case would be syenite or syenitic gneiss. Though an exposure of this rock may not be rich in magnetite, there is always the possibility that some other portion of the same body concealed under the drift may be locally enriched to the condition of ore. The determination of the approximate location of these concealed portions would, as in the previous case, be a preliminary to further magnetic prospecting, but as has been said before, ores of this latter type are not at present desirable enough to warrant any expenditure for prospecting purposes.

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SOME REGIONALLY METAMORPHOSED ORE DEPOSITS AND THE SO-CALLED SEGREGATED VEINS.[1]

WILLIAM H. EMMONS.

INTRODUCTION.

In the summer of 1909 the writer studied in detail certain pyritic ore bodies in Maine and New Hampshire which proved to be pre-Silurian regionally metamorphosed deposits of varied types. They are, for the most part, metamorphosed replacement deposits in quartzose schist, but one of them is probably a regionally metamorphosed contact metamorphic deposit.

These deposits of northern New England are types of the so-called "segregated veins" and have been described as such by many writers who have also described other deposits of similar characteristics. I think it highly probable that a large number of deposits in the eastern states and provinces are similarly metamorphosed and I have arranged the portions of various reports relating to genesis so that they may be more easily inspected from such a point of view. Among the common types of primary ore deposits we have the magmatic segregations, contact metamorphic deposits, deposits of the deep zone and deposits of the middle and upper zones, etc. Further these deposits are in places oxidized and some have been changed through process of secondary sulphide enrichment. It seems highly probable that each primary type and each secondary type may have a counterpart in the regionally metamorphosed deposits, and that the processes of regional metamorphism superimposed upon the several processes of primary deposition and secondary enrichment may have yielded the various types of the segregated veins. The field work was done by the U. S. Geological Survey in coöpera-

[1] Published by permission of the director of the U. S. Geological Survey.

tion with the state of Maine. I acknowledge my indebtedness to Messrs. G. O. Smith, E. S. Bastin, W. H. Weed, J. F. Kemp, Thos. L. Watson and others whose papers have supplied a considerable part of the data presented herewith.

GENERAL STATEMENT.

In eastern North America from Quebec to Georgia and westward as far as Ducktown, Tenn., there is a belt of old rocks nearly everywhere intensely dynamo-metamorphosed which at many places inclose deposits of pyritic copper ore. These deposits are unlike in some respects but have certain features in common. The members of the group here treated have in general the following characters: They are inclosed in schists of various kinds—quartz schists, mica schists, chlorite schists, chlorite-biotite schists and actinolite schists; the ore bodies are oriented parallel or nearly parallel to the schistosity and at many places the ore bodies are lenses which in a single mine are parallel and usually overlapping. The lodes are from one to one hundred feet wide and many of them persist along the strike for several hundred feet. They once supplied a large part of the copper of the United States and today yield large quantities of that metal and sulphuric acid. The most abundant ore minerals are pyrite, pyrrhotite and chalcopyrite, but galena, zinc blend, arsenopyrite, bornite, tetrahedrite and stibnite are found in many of these deposits. Some gold and silver are usually present. The copper-bearing oxides and secondary sulphides are often developed near the surface, especially in the southern part of the area which has escaped glaciation. The gangue minerals include chlorite, biotite, muscovite, quartz, calcite, garnet, tremolite, actinolite and zoisite, but all of these minerals are not present in each deposit. In those deposits which I have visited there is no evidence of hydrothermal metamorphism of the wall rock of the same character which is common in the younger deposits of the western states, and from published descriptions I think this feature is characteristic of the group. The deposits have been described by many able observers and their genesis has been much discussed, but so far as I am aware there are some important fea-

tures of their history which are still in doubt. J. D. Whitney[1] as early as 1854 applied to them the term "segregated veins." He says:

> These deposits wherever examined are found to exhibit a striking similarity to each other; they are never found in well developed transverse or fissure veins but form masses parallel with the formation and possess all the characteristics of segregated veins, or if, as is occasionally the case, crossing the strata at an angle, such branches are found subordinated to the segregated masses and not exhibiting in an unmistakable manner the phenomena of fissure veins.

Charles Hitchcock in 1878 described the deposits of Gardner Mountain, Grafton County, and the Milan mine, New Hampshire, and gives the following summary of their genesis:[2]

> The veins are usually in broad belts of intermingled and siliceous layers. They may be one, two, or more feet wide so close together as to be practically from 6 to 10 feet broad. . . . Our theory as to the origin of the deposits has been that they were originally beds not fissure veins and that in later periods the copper has been segregated from the general metalliferous belt into several strings and veins making up the richest portions. I have thought the continuity of the vein is to be seen in the presence of a series of lenticular patches or bonanzas not succeeding each other on absolutely the same plane but overlapping.

A. F. Wendt described the metallurgical features of the ores in 1886.[3]

Robert Hunt[4] states that "the segregation veins may be considered contemporaneous or may be produced during the infiltration of solutions after the rock has partly consolidated either by the action of heat or the influence of time." As an illustration of segregation he likens the process to placing fine unglazed earthenware in copper sulphate solution. As the solution passes through and is evaporated on the interior surface, metallic copper is deposited on the porous china.

J. F. Kemp, in the 1906 edition of "Ore Deposits of the United States and Canada," describes a number of these deposits.

[1] "Metallic Wealth of the United States."
[2] "Geology of New Hampshire," Vol. III., ECONOMIC GEOLOGY, p. 38.
[3] *School of Mines Quarterly*, VII.
[4] *British Mining*, 1887, p. 346.

His summary of the genesis of the Ducktown deposits, which are the most important members of this group, is given on page 775.

W. H. Weed[1] described a number of the deposits of this group and compared them with other deposits of the Appalachian states. He says of certain segregated deposits in basic rock:[2]

> The minute copper contents of diabase and diorite are sometimes segregated by solution at the same time and as part of the process of metamorphism which transforms the igneous rocks into amphibolite.

He does not imply, however, that such segregation is the usual genesis of the schistose ores.

Any geologist who has seen the segregated deposits will recognize the difficulties inherent in the problem of their genesis. The center of the lode is often massive sulphides which appear to be in all respects like any unmetamorphosed sulphide deposit in the younger rocks of the West. In hand specimens it shows no sign of schistosity or lamination, but along the margins of the deposit where portions of the country rock are involved with the sulphides, thin pyrite bands and quartz bands alternate with the bands of schist and all are crumpled together. Bands of pyrite intensely crenulated may make out into the country rock. The relations too may further be obscured by post-mineral planes of fracturing or slickensiding near the walls. Because of these features some observers have regarded the massive ore near the center of the lode as a later introduction in the older crumpled bands of iron sulphides and country rock, but when one attempts to map ore of two generations he is forced to conclude that it is all of the same age, for the massive pyrite and the schistose country rock with crumpled pyrite bands show every stage of gradation one into the other. Some fortunate exposures in the Milan Mine, New Hampshire, show that the ore has been faulted at the zone of flow for the country rock and that it is therefore older than regional metamorphism. In the region of Blue Hill,

[1] "Types of Copper deposits in the Southern United States," *Trans. A. I. M. E.*, Vol. XXX., p. 449. U. S. Geol. Surv. Bull., 225.

[2] "Copper Deposits of the World," 1907, p. 80.

Maine,[1] the geology and structural relations of the various rocks have been worked out by G. O. Smith, E. S. Bastin and C. W. Brown with such satisfying exactness that the relative age of the ore deposits may be stated with great confidence. These deposits are pre-Silurian, possibly Cambrian or pre-Cambrian. They include a schistose, garnetiferous sulphide deposit which is believed to be a regionally metamorphosed contact metamorphic deposit, and a number of the segregated veins so-called which are regionally metamorphosed deposits, which at one time were presumably fissure veins of the replacement type. The separation of the ore bodies and the behavior of the sulphides and gangue minerals in the zone of flow for the schist is peculiar and suggestive and I believe that a knowledge of the processes involved will be a step toward the solution of the genesis of this important group of deposits.

DEPOSITS AT BLUE HILL, MAINE.

The deposits at Blue Hill, Maine, are on the south coast east of Penobscot Bay. The mines are reported to have produced something over 2,000,000 pounds of copper. The country is an area of quartzites and siliceous shales and igneous rocks which have been intensely regionally metamorphosed. These rocks are overlain by unmetamorphosed Silurian limestone and cut by granite. Some ore deposits have been deposited by solutions from the latter but these do not come within the scope of the present discussion. The pyritic copper deposits are older than the regional metamorphism and much older than the granite which is not regionally metamorphosed. The deposits are inclosed in quartz biotite schists and in schistose volcanic rocks and are oriented approximately with the schistosity. They strike eastward and dip to the south. They are from five to twenty feet wide and persist for several hundred feet along the strike. The central portion of the lode is as a rule composed of massive pyrite and a smaller amount of quartz. Some chalcopyrite and

[1] Smith, G. O., Bastin, E. S., and Brown, C. W., U. S. Geol. Survey, Folio No. 149 Geol. Atlas of the U. S.

other sulphides are intergrown with the pyrite. Toward the walls of the deposits thin slabs of schistose quartz and chloritic rock are included in the pyritic ore and the orientation of the slabs and their constituent minerals is nearly parallel to the schistosity of the country and the orientation of the deposit. The walls themselves, which are of the same composition as the slabs, contain stringers of pyrite. There is thus a gradation from the center of the deposit which is in the main massive pyrite to the country rock which carries only a little pyrite. Comb structure and druses with crustified banding are wanting. At some places, notably in the Twin Lead and Tapley mines, small veins of the sulphides are crumpled parallel to the crumpling of the schist.

The behavior of the sulphides under regional dynamic metamorphism is noteworthy. Where the ore is nearly pure sulphide, composed of pyrite with some chalcopyrite, it is crushed and recemented by pyrite or by chalcopyrite. It then appears massive and shows little or no schistosity and one examining the central part of the lode only would not suppose it had been deformed with the metamorphism of the schists. But near the walls, in the lower grade ore composed of pyrite, quartz, chlorite and mica there is a well-defined schistosity. From microscopic studies it is seen that some of the crushed fragments of pyrite have oriented themselves parallel to the schistosity between the grains of quartz and chlorite. The crushing is especially well shown where two crystals of pyrite are pressed against each other or against a grain of quartz. If the pyrite crystals are surrounded by chlorite or by mica, they are protected by these yielding minerals which wrap around the pyrite, but where two pyrite crystals touch they are shattered. Some crystals of pyrite are formed, however, from iron sulphide dissolved and reprecipitated and the most perfect crystals are to be found in thin crumpled seams when the movement has been most intense. Under these conditions cubes and octahedra are developed rather than the pyritohedron or pentagonal dodecahedron. The deposition of pyrite was in perfect crystals even under the conditions of great pressure and in the presence of other minerals.

The great power of the crystallizing force which operates when pyrite is formed is well known. It is so great that when pyrite replaces other minerals exactly enough of the other minerals is dissolved to make a space for the pyrite. As an example of this may be cited the common case of quartzite in which two rounded grains of quartz are half dissolved and one perfect pyrite crystal fills completely the parts removed in the two quartz grains.

It is no easy task to determine the character of these deposits before they were metamorphosed, but this may be inferred from their present condition and mineralogical character. The diagnostic value of the minerals is prejudiced, however, since nearly all of them may be produced under conditions of regional metamorphism where the necessary elements are at hand. Before metamorphism the pyritic copper deposits of Blue Hill and Brooksville were presumably fissure veins of replacement types and disseminated ores along fractured zones.

DEER ISLE MINE.

At the Deer Isle mine on Denbow Point, Deer Isle, a lode following the schistosity dips northward about 45°. The deposit is in the Castine series which consists of surface volcanics and calcareous water-laid tuffs. The New Haven greenstones, in part intrusive igneous rocks, outcrop a few feet away. The deposit is a lode from one to eight feet wide and of unknown vertical or horizontal extent. It is composed of sheets of pure sulphide an inch or two wide which persist for several feet along the dip and strike and are overlapped by similar sheets. The rock between these is composed of innumerable paper-thin plates of alternating sulphides and garnet. The sulphides are steel-colored zinc blend, pyrite, galena and chalcopyrite. Intergrown intimately with them is a considerable amount of magnetite. The gangue minerals are garnet, actinolite, sericite, calcite, chlorite, quartz, barite and rhodochrosite. Without doubt the deposit has been regionally metamorphosed since it was formed, and the highly schistose structure of the lode which parallels

that of the country rock has resulted from the same dynamic forces which developed the schistosity in the country rock. The minerals are similar to those of contact metamorphic deposits but they have been rearranged by regional metamorphism.

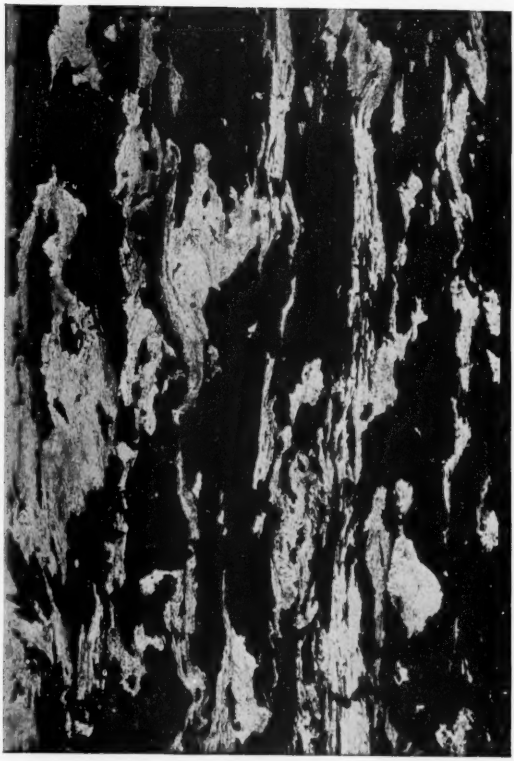
The sulphides have been crushed, recemented and in part recrystallized. The chlorite and mica seem to have been completely dissolved and recrystallized with longer axes parallel to the schistosity and to the orientation of the lode. The garnet is so highly fractured that in places it is almost opaque in thin sections. None of the garnet shows the crystal form. Garnet, as is well known, is formed in igneous rocks, in contact metamorphic deposits in some veins of the deep zone[1] and by regional metamorphism. In igneous rocks it is nearly always idiomorphic. In contact metamorphic deposits it is either massive or idiomorphic and very often shows such optical anomalies as double refracting rings. It may appear to have the schistose structure where it replaces schists in contact metamorphic deposit, but it is not highly cracked and some of the garnets usually have the crystal outline or else show the double refracting rings. In the veins of the deep zone it is usually idiomorphic.

The garnet of the Deer Isle mine is not idiomorphic. Under the microscope it has the color and general appearance of andradite and without much doubt is contact metamorphic garnet which has been regionally metamorphosed. Plate IX. is a photomicrocrograph of this ore. The light areas are chlorite and sericite. The dark areas are sulphide and garnet, the latter predominating. The garnet is so highly crushed that it lets through very little transmitted light and is, therefore, nearly dark where the nicols are not crossed.

MILAN MINE, NEW HAMPSHIRE.

The Milan mine is located in Coos County, northern New Hampshire, in the foothills of the Presidential Range. It is about eight miles northwest of Berlin and is connected by sur-

[1] Waldemar Lindgren, ECON. GEOL., Vol. II., p. 448.



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[1] "Min.

face tramway with the Marston siding of Grand Trunk Railway. The deposit was discovered in the seventies and was worked steadily until 1886. According to Herbert A. Davis,[1] the monthly production was 2,600 tons, and this production was presumably sustained for several years. It is producing steadily at the present time.

The country rock at the mine is a highly metamorphosed siliceous schist. In the underground workings which do not go far into the country rocks there are no pure quartzites, limestones, or conglomerate layers, or grains of grit, bedding planes, or other characteristics of sedimentary rocks which would show its clastic character. It has well-defined planes of schistosity which near the mine strike northward and dip westward from 30° to 90°. Locally, they dip eastward at very high angles. The microscope shows the schist to be composed of quartz, chlorite, biotite, muscovite and pyrite. The quartz grains are oriented parallel to the mica and chlorite flakes.

On the surface, perhaps one fourth mile northwest of the mine and between the mine and the railroad track, beds of highly siliceous schists outcrop at many places. Some of these rocks contain a myriad of thin, dark, actinolite fibers. Where subjected to weathering the siliceous schist shows the rounded grains of a fine quartzite. The wall rock of the mine is less siliceous than the quartzite and contains a greater percentage of chlorite, biotite and muscovite. Mineralogically the wall rock is such as may have resulted from the intense regional metamorphism of a quartz-rich shale or clayey quartzite and there is nothing in its general appearance and mineralogical composition which is inconsistent with a sedimentary origin.

On the 115-foot level of the mine, about 35 feet northwest of the shaft, there is about three feet of an actinolitic schist which is different in appearance and mineralogical composition from the biotite schist which constitutes the walls at most places. It has a dark, fine-grained groundmass which contains abundant crystals of hornblende about 1 mm. thick and 1 cm. long.

[1] "Min. Res. of U. S.," 1885, p. 501.

Under the microscope the hornblende shows characteristic cleavage and is surrounded by a groundmass of fine quartz and clouded sericitic bodies which are probably decomposed feldspars. It contains also some chlorite, magnetite and calcite. According to Hitchcock the granite gneiss outcrops not far from the mines.

The deposits are overlapping pyritic lenses parallel to the schistosity of the country rock. The gangue is quartz, chlorite, black mica and white mica. The sulphides are pyrite, chalcopyrite, zinc blend, galena, bornite and chalcocite. Little or no magnetite is present and pyrrhotite was not noted in several tests that were made. It is mentioned, however, as occurring in the ore in a list of minerals of New Hampshire, published in 1886.[1] The ore carries $1.50 gold and about one ounce silver to the ton. Much of the ore is solid pyrite, which includes fragments of the banded schists oriented parallel to the walls. Here and there the pyrite is cut by quartz stringers. Some of the sulphide ore, notably in the crosscut to west on south end of 115-foot level, is massive zinc blend, carrying well-formed crystals of pyrite, 1 mm. in diameter, with here and there small specks of galena. In the stope at the north end of the 115-foot level and between the 115-foot level and 70-foot level above the main ore body, there is a mass of white quartz cut by veinlets of galena and pyrite with specks of those sulphides scattered through it. Below this ore the vein consists of pyrite and chalcopyrite cut by innumerable fracture planes which are filled with paper-thin films of chalcocite, the whole carrying 12 per cent. copper.

The ore bodies are two overlapping lenses separated by 10 or 15 feet of chlorite schist. They strike a few degrees east of north and dip steeply westward. They are not tabular but broadly they approach this form. In detail, however, they are characterized by gentle undulations along both the dip and the strike and at places there are bends of more than 45° both in dip and strike. The south ore body outcropped on the present

[1] "Min. Res. of U. S.," p. 757.

FIG. 1.

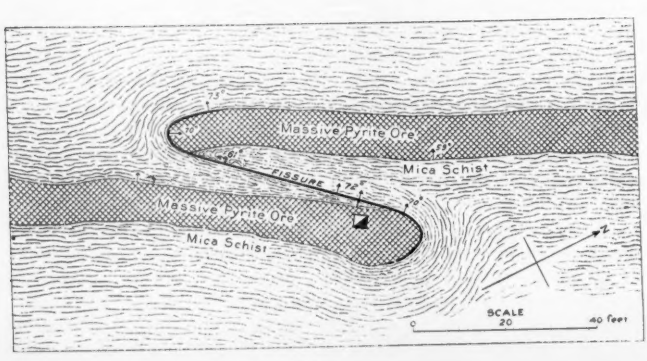
Massive Pyrite Ore
Mica Schist
FISSURE
Massive Pyrite Ore
Mica Schist
SCALE
20
40 Feet

FIG. 2.

site of the mill and the mine was first worked in an open cut from 15 to 25 feet wide, which extends 200 feet along the strike. As developed it is from 5 to 25 feet wide and like the north ore body it dips steeply westward. Near the surface it is developed southward for 275 feet along the strike. At its northern termination the end of the ore pitches southward at a low angle. On the 70-foot level the termination of the shoot is 45 feet from the shaft and dips toward it from 50 to 70 degrees, becoming steeper in depth. Near the end of this lens, at the pump station below the 115-foot level, the ore is highly crumpled near the termination.

The ore bodies are parallel to the schistosity. At some places the walls are intensely crumpled and much of the milling ore consists of the thin alternating bands of schist and pyrite intimately interbanded and crenulated. Fig. 1, Pl. X., is a photograph of a polished surface of this ore. The seams of pyrite and quartz are parallel to the schistosity of the country rock and are clearly metamorphosed by the same crumpling movements and the ore is undoubtedly older than the metamorphism of the schists. At many places it grades into the pure massive pyrite ore but the latter does not show any schistosity. There is no noticeable sericitization or other hydrothermal metamorphism of the walls or any leaching of the wall rock, such as is characteristic of most ore bodies not regionally metamorphosed, and the ore at no place shows comb structure, crustification or druses.

The plan of the 115-foot level, Fig. 2, Pl. X., illustrates further the effects on the ore body of the regional metamorphism due to intense shearing movements under load, which developed the schistose structure in the country rock. Before shearing the ore body was probably a single tabular mass, but by these movements was thrust endwise upon itself so that it divided and overlapped. The division or fault took place in the zone of flow for the schist and was a pulling apart, not by a sharp cleavage, but rather as a somewhat yielding body is divided. A tight fissure dipping westward at about the same angle as the two ore bodies joins the two ends and wraps around the ore at both terminations. The schistosity likewise wraps around the

ends of these ore bodies and parallels the fissure which joins them. This relationship of the schistosity to the line of movement which separates the two lenses shows that the ore body has been subject to the same earth movements as the rock. Since it has separated in the zone of flow it must have been deposited before the last regional metamorphism of the country. This is further indicated by the gradation of the massive pyrite ore to pyrite containing parallel quartz and mica bands, to quartz biotite with numerous thin bands of pyrite, and this into the schist with only an occasional band of pyrite to nearly pure schist. Thus the rocks show bands of the schist and bands of the pyrite varying in all proportions along the wall, and the ore always has the minutely schistose structure wherever it contains quartz and mica. The main lode of pyrite ore has exactly the same character as the smaller massive layers and must have the same origin, but where pure and large it is as free from conspicuous marks denoting movement as any ore deposit in unmetamorphosed rock. Some of the crystals of pyrite have perfect form when included as the thinnest seams between the quartz-rich or biotite-rich layers of the schist. As these pyrite seams increase in size and purity they become more massive and when silica minerals are absent the ore does not show any lamination parallel to the schistosity of the country rock whatever, although the ore is as already stated older than the metamorphism of the schist and partook in the movements of metamorphism. The aluminous, more or less plastic wall rock was capable of crumpling to gnarly schistose layers, and where the seams of pyrite alternate with thin seams of quartz the same schistosity is shown, but massive pyrite ore not containing quartz or clayey material, adjusts itself to conditions of pressure without leaving a conspicuous record of the movements. The pure pyrite is at no place laminated. The larger bodies have broken and have been cemented by pyrite or chalcopyrite and the smaller crystals have completely crystallized. Galena and zinc blend have also recrystallized, but some of the chalcopyrite shows faint lamination.

This feature of chalcopyrite was noted also in the Tapley mine near Blue Hill, Maine.

At the south end of the north ore body on the 115-foot level the ore is highly siliceous and consists of intensely crumpled pyrite and quartz. At this place, where the ore body pulled apart and became two lenses the ore looks like a surface of gnarled oak or vermicelli. Here the schistosity of the walls instead of striking northward parallel to the main lode strikes westward parallel to the end of the lens. On an intermediate level, just below, near the pump station, the same intense crumpling is shown at the north end of the south ore body.

These places show that the ore body broke where it was most siliceous, and where most heterogeneous and because of that heterogeneity of composition the movement was best recorded in the ore itself. If it had been pure pyrite instead of quartz-pyrite-chlorite ore it would not have shown the intense crumpling for the pyrite would have broken and recemented into an apparently homogeneous mass.

Genesis.—The deposit was at one time a large mass of ore contained in impure quartzite or in schist which was less intensely metamorphosed than at the present time. The ore may have been deposited at the time the granular rocks of the "lake and granitic gneiss" were erupted, or at the time of the intrusion of a basic igneous rock which is now actinolite schist. It was not, however, a contact metamorphic deposit, for it has none of the characteristics of such a deposit and it does not contain garnet and epidote and other lime silicates which are usually found in such deposits. It was presumably a deposit first formed at moderate depth, and it consisted of quartz, pyrite, zinc blend, galena and chalcopyrite. Some aluminous material was present —either clay or sericite. The walls near the vein were presumably replaced by pyrite and other minerals. It was deeply buried after deposition for it was intensely deformed in the zone of flow at the time when the siliceous shales were subjected to regional metamorphism and changed to schists, or at the latest before this process had ceased to operate. During the process

of metamorphism the deposit was deformed by pressure. Certainly it was pulled apart at one place and thrust back on itself so that the two ends overlapped some forty feet. The ore body pulled apart where it was most siliceous, where parallel sheets of quartz and mica are abundant in the pyrite, and because of this circumstance of heterogeneity also, a maximum of squeezing and crumpling was recorded. The sulphides were crushed, recemented and at some places dissolved and reprecipitated. Drusy cavities, banded and comb structures, if present, were destroyed. Any evidence of hydrothermal metamorphism along the walls of the deposit were obscured by the subsequent regional metamorphism of the deposit and the country rock.

AMMONOOSUC DISTRICT, NEW HAMPSHIRE.

Some forty miles southwest of Milan, at Gardner Mountain in the Ammonoosuc mining district, New Hampshire, the same rocks are exposed as those which are associated with the Milan copper deposits. These rocks at Gardner Mountain are intensely folded Huronian schists of the Lyman and Lisbon groups associated with which is a gneiss, possibly an intrusive in them. A number of deposits are located in this area and they are for the most part lodes of pyrite, pyrrhotite and chalcopyrite interbedded with the schistosity. In the late seventies five mines were working in this district. According to a statement of Hitchcock[1] the country rock and ore are essentially the same as at Milan. In the zinc mine at Warren quartzose ore containing most of the common sulphides is "crossed by a mass of tremolite." The lodes are faulted by trap dikes presumably of much later age. In the Ammonoosuc district the "auriferous conglomerate" is the upper member of the Huronian. This conglomerate carries gold at many places but Hitchcock does not state whether the gold is primary in the pebbles or is a later introduction. The presence of quartz pebbles among those of the earlier Huronian rocks suggests the probability that mineral veins existed in this country before the close of the Huronian.

[1] "Geol. of New Hampshire," Vol. III., ECON. GEOL., p. 47.

Mr. R. W. Richardson informs me that he has found gold nuggets in the auriferous conglomerate which appeared to be water-worn but distorted by metamorphism.

ELY, VERMONT.

The country rock at Ely is biotite schist greatly folded and cut by granite. The ore minerals are pyrrhotite, chalcopyrite, some pyrite and zinc blend. The gangue is quartz, actinolite, and garnet. The ore carries some gold and silver. The deposits at the Union mine in Corinth are parallel to the schistosity. According to Weed the ore forms lenses which overlap and on going down where one plays out the tapering body of another lens overlies the lower end of the upper body. Four or five times in sinking the Elizabeth incline the ore was lost but winzes sunk in foot wall found the overlapping body. Along the strike the ore may end in a blunt wedge, may fork in thinning wedges, or grade into country by increasing "slaty" material. The ore bodies at the Elizabeth mine are from 35 to 100 feet wide; at Ely the overlapping lenses continue for 3,400 feet to the bottom of the flatly inclined shaft.

With respect to the genesis of these deposits we have the high geological authority of H. L. Smyth and P. S. Smith[1] that they were deposited since the metamorphism of the country. A photograph[2] of a surface of the Ely ore shows that the sulphides are concentrated in the axes of crumpling of the saddles and troughs of the minute anticlines and synclines of the crenulated schist. The photograph is almost identical with Fig. 1, Pl. IX., of this paper, which shows the ore of the Milan mine, but in the latter the pyrite is highly crushed and recemented and was present during the regional metamorphism, for the ore body was faulted in the zone of flow. In the Milan ore it collected in the minute anticlines and synclines, not because they were open spaces, but because they were places of least pressure. The point has been made that the Barre granite causes tourmalinization and that associated pegmatites contain chalcopyrite and the mineralization

[1] *Eng. and Min. Jour.*, April 28, 1904, p. 677.
[2] W. H. Weed, "Copper Mines of the World," p. 264.

has been attributed to solutions from the granite. On the other hand the overlapping character of the lenses of ore at the various mines is characteristic of regionally metamorphosed deposits and elsewhere the unmetamorphosed granites of northern New England were not copper rich magmas. The ore deposits associated with those of Maine are of silver, lead and molybdenum, with never more than a very small amount of chalcopyrite. But the granite in the Elizabeth Mine is replaced by ore and there must have been some mineralization or at least rearrangement of minerals as a result of the intrusion. If the chief mineralization occurred at that time the deposit is unique in New England and would have a closer genetic connection with certain gold deposits of the southern Appalachians.

DAVIS, FRANKLIN COUNTY, MASS.

At the Davis mine,[1] Franklin County, Mass., a pyritic vein, from 12 to 22 feet wide and 700 feet long, parallels the schistosity of chloritic micaceous schist (Savoy Schist) dipping at an average angle of 18°. This deposit has been steadily worked for many years. The ore yields sulphuric acid and copper. According to B. K. Emerson,[2] the minerals of this deposit include pyrite, chalcopyrite, pyrrhotite and quartz. The ore carries 1.5 per cent. of copper.

ADAMS COUNTY, PENNSYLVANIA.

The copper deposits of Adams County, Pa., which have been described by J. Trowbridge Bailey,[3] are enclosed in quartz-chlorite-epidote-schists, which are cut by an intruding quartz-epidote rock. The ore is schistose and consists of sulphids and native copper. Much of the epidote is impregnated with copper.

C. Hanford Henderson,[4] describing one of these deposits located on the summit of Musselman hill, states that in the bot-

[1] "Min. Res. of U. S. for 1883," U. S. Geol. Surv., p. 878.
[2] "A Mineral Lexicon of Franklin, Hampton and Hampden Counties," Bull. 126, U. S. Geol. Survey.
[3] *Eng. and Min. Jour.*, 1883, p. 88.
[4] *Trans. A. I. M. E.*, XII., p. 85.

tom of a fifty-foot shaft, an epidotic rock carrying up to 5 per cent. copper, mainly native, is enclosed by chlorite walls.

CAPLETON, QUEBEC.

In Quebec, at Capleton, near Sherbrooke, a large number of deposits yielding acid, copper, gold, silver, lead and zinc are inclosed in schistose rocks which from published descriptions are probably the same as the schists of Milan.[1] Dioritic greenstone is associated with the schists. The lodes which generally conform with the schistosity of the rocks are highly pyritiferous and commonly carry pyrrhotite and magnetite. The Capleton, Eustis and Albert mines are owned by the Nichols Chemical Co., of New York, which has for many years exploited these properties for sulphur and the metals. The deposits are in many respects similar to the metamorphosed ore at Milan. One ore body from 45 to 60 feet wide has been worked to a depth of over 1,500 feet.

NEWFOUNDLAND.

There are several segregations or impregnations of pyritic ore in chlorite schist in the vicinity of Notre Dame Bay, Newfoundland. These deposits have been described by M. E. Wadsworth in the *American Journal of Science,* series III., vol. 28, p. 102. He says:

> The Betts mine is in argillite, chlorite schist and diabase. The ore band runs east and west, and is cut by north and south diabase dikes. . . . All the ore of importance is found in the schistose portions formed from the altered argillite and diabase. The ore is a segregation in the broken fissured altered portions of the rock, and occurred in immense irregular masses. The ore is chalcopyrite mixed with pyrite, quartz, etc. The foot wall is formed by diabase.
>
> The upper portion of Little Bay Mine is in chlorite schist impregnated with chalcopyrite. The whole is longitudinally cut by a dike parallel with which run three bands of chalcopyrite which lie near the dike. This deposit was an immense lenticular mass of schist impregnated with impure chalcopyrite, the widest portion being on the surface and gradually narrowing in depth. . . . The mode of occurrence of the

[1] Ells, R. W., "Geol. Survey of Canada," Vol. IV., p. 53, also *Trans. A. I. M. E.*, vol. 18, p. 319.

copper ores in northern Newfoundland, taken with the geological structure of the country, indicates the following as their origin. The schistose rocks have been cut by dikes of eruptive basaltic rocks. During the time of this eruptive activity, after the chief portion of this basalt had been extravasated, the action of percolating thermal waters on the eruptive rock and its fissured and broken adjoining sedimentary rock, led to the concentraton and deposition of the copper, iron, and quartz in the places in which they are found. The copper is here thought to have been brought up from below finely disseminated through the basaltic material and later concentrated by the percolating waters.

The Virgilina District in Virginia and North Carolina has been described by W. H. Weed.[1] The country rock is schist and gneiss which Mr. Weed considers of igneous origin. They include andesites and altered andesite tuffs and are cut by dikes of diabase. In general the veins strike from N. 5° E. to N. 10° E. and are arranged with overlapping ends. Some are parallel to the schistosity and some cross it. The veins are lenses connected by strings of quartz. Commonly the quartz is incased in shells of micaceous schist, and many thin films of the schist are included. Neglecting the oxides, the principal minerals are quartz, calcite, epidote, pyrite, chalcopyrite, chalcocite, bornite and grey copper. Banding is common, but is due to included schist.

These veins are commonly regarded as having been deposited in openings in the schist and later than the metamorphism of the country, but one searches in vain through the excellent descriptions for any record of crustification, vugs or druses which should be expected in such deposits, and the numerous drawings of Weed show none. Describing the Blue Wing vein he states, "The ore body often presents a streaked or ribboned appearance due, not to crustification or to recent movements of the vein, but to partly replaced sheets of slate." The drusy quartz of the High Hill he states is distinctly secondary.

The genesis of the Virgilina ores is of the greatest importance, for in these deposits alone, so far as I am aware, has primary chalcocite been found. If chalcocite is formed by ascending thermal solutions this fact should be generally recognized. Its economic importance is too obvious to require comment here.

[1] *Trans. A. I. M. E.*, Vol. XXV., p. 453.

L. C. Graton made a visit to Virgilina in 1906 and in the "Mineral Resources" for 1907 (p. 620) he states that the chalcocite in these veins is primary. His wide experience with chalcocite ores renders his opinion especially valuable. He showed some ore from Virgilina which differs from the common type of chalcocite in that it has none of the common secondary structures and seemed to be from a vein too tight to have been formed by descending solutions. The hypothesis that the ores are, in part, regionally metamorphosed secondary sulphides is attractive, since it explains some puzzling features of the deposits.

THE ORE-KNOB-GOSSAN LEAD DEPOSITS OF NORTH CAROLINA AND VIRGINIA.

Some of these deposits were described by T. Sterry Hunt,[1] who compares them to the Ducktown deposits and states that the black ores of copper were opened up for more than a mile. Large quantities of copper were taken from these deposits in antebellum days.

The country rock is mica schist. The deposits are tabular bodies which strike northeastward but are not quite parallel to the schistosity. This unoxidized ore is chalcopyrite, pyrrhotite, pyrite, magnetite, sphalerite, quartz, garnet, epidote, hornblend and calcite.

GOLD HILL DEPOSITS.

This district has produced considerable gold and copper. The country is an area of schist carrying auriferous quartz veins which are in general parallel to the foliation and are linked by quartz stringers. The sulphides are pyrite and chalcopyrite. Some of the ore is, according to Weed,[2] a breccia of silicified schist. The schist was presumably metamorphosed before the ores were deposited. "There is no banding or crustification." Possibly some regional metamorphism of the milder type has taken place since the more intense metamorphism and since the

[1] *Trans. A. I. M. E.*, Vol. II., p. 127. E. E. Olcott, *Trans. A. I. M. E.*, Vol. III., p. 391.

[2] Weed, *Trans. A. I. M. E.*, Vol. XXX., p. 474.

ores were deposited, but there is no reported evidence of this, and the ore minerals do not include those which are commonly found in regionally metamorphosed ores.

SEMINOLE MINE, GEORGIA.

The Seminole copper mine, located at Lincoln, Georgia, has been described by Thos. L. Watson.[1] The country rock is a quartz-rich biotite sericite schist, which like the ore, is cut by many schistose dikes composed of feldspar, hornblend, biotite and much quartz. A more acid igneous rock also occurs near the deposit. The ore is composed of chalcopyrite, galena, sphalerite and pyrite and alteration products and carries gold and silver. The lodes are possibly a few degrees off the schistosity. Of the ores Mr. Watson says:

> Like the country rock proper, they are throughout thinly laminated or schistose in structure. The ore is distributed through the veins in the form of stringers, irregular bunches, or nests, and as large and small disseminated grains and particles. The ore occurrence as disseminated grains or particles closely resembles that of the inclosing rock, except that in the veins the mineral particles are in a more localized and concentrated form. The ore distributed through the surrounding rock, particularly the pyrite, is invariably in the form of large and small cubical crystals. The central portions of the vein are characteristic and are sharply differentiated from the inclosing rock, while the outer portions next to the wall appear less easy of differentiation from the schists in many places. Lenses of varying sizes, composed of schists similarly silicified and mineralized as the true veins, occur between the veins and in some instances afford equally as good ore. These lenses may be spaced at wide intervals or they may occur close together.

Of the genesis Mr. Watson states:

> From the available field evidence the order of events, so far as it has been possible to interpret them, are, in general, as follows: An early period of intense dynamic disturbance caused extensive crushing and fracturing of the country rocks, resulting in secondary structure. This was followed by silicification and mineralization concentrated along fairly well-defined, roughly parallel lines marking the present veins. A second period of disturbance resulted in the intrusion of the rocks

[1] Bull. 225, U. S. Geol. Surv., p. 182.

of basic igneous dikes. Finally, there was a third period of dynamic action, which rendered the massive dikes schistose in structure and caused further mineralogic alteration of the dikes into forms unlike the original eruptives. Necessarily the second and the last periods of disturbance increased the metamorphism of the country rocks and aided in the mineralization.

Since the ore is cut by schistose dikes, it is certainly a regionally metamorphosed deposit. Mr. Watson's description of the central portion and edges of the lode would serve almost as it stands for some of the deposits in northern New England.

DUCKTOWN, TENN.

The Ducktown ores are large lenticular bodies of copper bearing sulphides in quartz mica schist. Commercially they are by far the most important copper deposits of the Appalachian states. T. Stery Hunt[1] regards the deposits as filling rifts and fissures. According to Carl Henrich[2] they are replacements of dikes of pyroxene rocks which cut across the schistosity along fault fissures. W. H. Weed, who visited these deposits subsequently, takes issue with Henrich at many points. He considers the country rock metamorphosed sediments and the deposits replacement veins. The minerals are pyrrhotite, chalcopyrite, pyrite, galena, zinc blend, calcite, zoisite, quartz, garnet and actinolite. No banding or crustification is found in the deposits and from this it is assumed that they are replacement deposits and not the filling of open spaces. The association of minerals and the form of the ore bodies are significant and suggest a genesis similar to those described above. J. F. Kemp[3] gives the following summary of the history of these deposits.

By a process of regional metamorphism, a sedimental series of shales and sandstones was altered to mica schists and quartz schists. Where the ore is now found, zoisite, tremolite and garnet were also produced, but it is not known whether they are met outside of the mines or not. They indicate the former presence of magnesian and calcareous rocks, although, generally speaking, lime is practically unknown in the meta-

[1] *Trans. A. I. M. E.*, II., p. 124.
[2] *Trans. A. I. M. E.*, XXV., p. 173.
[3] "Ore Deposits of the United States and Canada," edition of 1906, p. 192.

morphic rocks of the district, and the local waters are remarkably pure and soft. Whether a calcareous shale or an intruded dike yielded the lime silicates, or whether they are metamorphosed, calcareous, vein-material from an older vein-filling cannot be stated. After the general metamorphism, a series of dislocations was developed along the lines of the present veins, and pyrrhotite and sometimes pyrite were introduced. After the deposition of the pyrrhotite there was further movement, which shattered the pyrrhotite and allowed the introduction of chalcopyrite in streaks and fine veinlets all through it. Still later, and apparently after another movement, calcite came in and penetrated the shattered sulphides and older silicates. After the introduction of the calcite, by some movement fissures notably horizontal were produced, which became filled with glassy quartz, and which have yielded the so-called "floors." More or less contemporaneously with the quartz, coarsely crystalline pyrrhotite, chalcopyrite and blende were produced, which are in marked contrast with the earlier sulphides. The oxidation of the veins above the ground-water, the formation of the brown hematite outcrops and the development of the zone of enrichment (the black) bring the process down to the present.

DISCUSSION.

Physical Changes.—The regionally metamorphosed ore deposits are in the main parallel to the schistosity of the country rock or else cross the schistosity at small angles. This is in accord with the law that under stress in the zone of flow tabular bodies tend to orient themselves in the direction of least pressure or right angles to the direction of greatest pressure. Take the simple case of a quartzose shale which is squeezed in the zone of flow. The quartz particles which are relatively short in one dimension will revolve and orient themselves with their longer dimensions in the direction of least pressure. The micaceous minerals, chlorite, muscovite and biotite, will crystallize from the dissolved substances and likewise orient themselves parallel to the direction of least pressure. The large tabular bodies of sulphides do not move so freely, but evidently the same mechanical processes operate on them. Perhaps they act as buttresses and control the schistosity to some extent, but ultimately are brought into conformity with the direction of least pressure. Some of them are broken in the process which gives

rise to the parallel bodies *en échelon*—the lenses which nearly everywhere are overlapping.

The deposits studied are believed to have been in part replacement veins and if so such phenomena as crustification and symmetrically lined druses may never have been developed. If these structures were ever present they have been destroyed by regional metamorphism. Another feature of the regionally metamorphosed ore deposits is their great width in comparison to their length. As a class they seem to be wider than deposits not metamorphosed. This is just the opposite of what should be expected for, from internal evidence, one gets the impression that they have been squeezed thinner. Probably a large number of them have been flattened out to masses too thin to justify development and these have been overlooked, while the larger deposits only have attracted attention. Possibly some of them became thicker in the process of metamorphism through reverse faulting. The fissure shown in Fig. 2, Pl. IX., makes a very small angle with the two ore lenses. If this angle were decreased to zero and movement continued in the direction of the fissure, the reverse faulting would result in a thickening of the ore body. Indeed, this seems to have taken place on the level above that shown in Fig. 2, Pl. IX., where the two ore lenses were mined from the same stope. This process may compensate to some extent for those which tend to flatten the ore bodies.

Chemical Changes.—The changes which take place when rocks are deformed under deed-steated conditions have been fully discussed by Van Hise[1] and Leith.[2] Under such conditions the minerals are dissolved and are reprecipitated to form new minerals which are more stable under the new conditions of pressure. The medium through which the changes are carried on is the small amount of water trapped in the buried rock. The minerals formed under pressure are in part the heavy compounds such as garnet, staurolite, etc., but certain hydrous silicates such as chlorite, muscovite and biotite are extensively formed also. The chemical

[1] "Treatise on Metamorphism," U. S. Geol. Survey.
[2] "Rock Cleavage," Bull. of U. S. Geol. Survey.

changes are great, but deep in the zone of flow they are mainly those of solution and reprecipitation, and the water through which these changes are brought about probably moves in a very restricted sphere except that which moving gradually to points of less pressure escapes with CO_2 and other salts to the surface.

E. S. Bastin[1] has taken averages of hundreds of analyses of shales, slates, pelites and schists, and finds certain clearly expressed chemical relations which recur throughout the different series, exhibiting various degrees of metamorphism. His average analyses indicate in a broad way that beyond dehydration and some other minor changes, the changes in the chemical composition of a slate metamorphosed to schist are slight except for the water, some of which is driven out. The mineralogical changes are due to rearrangement of the elements of the shale or slate rather than to the introduction of new elements.

Although the ore and gangue minerals have a greater crushing strength than the aluminous minerals of the quartzitic shale and are therefore more capable to hold spaces open, the same principles will probably apply. The processes which operate in the regional or dynamo-metamorphism of the ore bodies are solution and reprecipitation, mashing and cementation. The elements are rearranged within the ore body; but little or nothing is added. The dissolving power of the included water is increased by heat generated by friction and precipitation is accomplished upon cooling after the stresses are relieved.

The Milan ore body, for example, is surrounded by yielding schists which under conditions of metamorphism were totally incapable of holding spaces open, and the fault shown in Fig. 2, Pl. X., could not pass through them. Thus the ore body was effectively sealed on both sides against extraneous solutions. The hypothesis that such supposed additions have come into the ore body through the agency of gases which are generally assumed to possess the power to penetrate more minute openings is probably untenable, for as shown by Van Hise the groundwater,

[1] *Jour. Geol.*, Vol. XVII., p. 445.

under conditions of normal increment of heat, remains liquid, owing to increased pressure, to very great depths.

At Blue Hill, Milan and Ducktown, chalcopyrite cements the broken pyrite crystals and this feature is possibly characteristic of these deposits as a group. Some of this chalcopyrite is not connected with any vein which might fill a fissure, leading to an outside source, and I believe that such chalcopyrite is merely the copper, iron and sulphur which were dissolved and reprecipitated just as pyrite was dissolved and reprecipitated. If so, then the copper-iron sulphide is more soluble under conditions of regional metamorphism than the iron sulphide.

According to Weigel[1] 70.1×10^{-6} mols of freshly precipitated FeS is dissolved in a liter of pure water at room temperatures and pressures, while only 3.51×10^{-6} mols of CuS is so dissolved, but possibly a mixture of the two $CuFeS_2$ (chalcopyrite) would be more soluble than either salt alone and would be precipitated last and in the cracks of the pyrite. Some simple chemical work on the relative solubilities of the common minerals in mine waters under pressure would supply badly needed data for a discussion of the reactions.

If these deposits are the metamorphosed equivalents of the various types of primary ores, the wall rocks should show the hydrothermal metamorphism which as a rule accompanies ore deposition. Since sericitization is the commonest type of such hydrothermal metamorphism, one should look for sericitization in the wall rocks of the deposits and in the schist included in the ore. In the deposits of Maine and New Hampshire chlorite, biotite and sericite are developed in the included wall rock, but they are also developed in the country far from the veins though possibly not so abundantly. This is certainly true in some of the minor deposits at Blue Hill.

In the wall rock of the deposits of copper ore in unmetamorphosed rocks chlorite is not usually an abundant mineral. It forms from ferromagnesian minerals when hydrothermal metamorphism is not too intense at some distance from the

[1] *Zeit. für phys. Chemie*, V., 58, p. 292.

deposit or in connection with solutions which deposit small lean ore bodies. Lindgren[1] has called it a transitional mineral. In the regionally metamorphosed deposits it is usually more abundant than sericite. Along the walls as elsewhere in the schist, it has presumably been formed in the process of regional metamorphism. The sericite, kaolin, pyrite and other minerals of the schist and ore supplied the elements necessary for the synthesis. The problem of magnesium offers some difficulties. It is commonly carried away during sericitization[2] and still it constitutes a large proportion of most chlorites. Possibly the chlorite near the ore deposits is abnormally rich in iron. At the Milan Mine the chlorite near the walls is of the blackish green variety and has the properties of the iron-rich perchlorite rather than the magnesia-rich clinochlore, but whether the reverse is true in the country rock far removed from the influence of possible pre-Silurian hydrothermal metamorphism cannot now be shown. Unfortunately the mine workings do not extend beyond the mineralized zone.

SUMMARY.

The deposits at Blue Hill and Deer Isle, Me., and at Milan, N. H., are regionally metamorphosed. The ore and the metamorphosed country rock grade into each other and microscopic study of the sulphides show that they are highly fractured. They are less highly fractured where metamorphism is most intense, for there they are recrystallized. Cubes and octohedra are characteristic crystal forms. Where the sulphides were only partially dissolved and recrystallized, chalcopyrite commonly cements the comminuted pyrite. The central portion of the lodes is composed mainly of massive pyrite and this shows no schistosity. It is fractured, however, and recemented as is shown under a hand lens or microscope, but in a hand specimen it resembles, in all respects, non-schistose ores. It is not a

[1] "Metasomatic Processes in Fissure Veins," *Trans. A. I. M. E.*, Vol. XXV., p. 578.

[2] Lindgren, Prof. Paper 43, U. S. Geol. Survey, pp. 167 and 168; Steitman, Econ. Geol., III., p. 381.

later introduction but was formed at the same time as the schistose ores along the walls of the deposits. It is not schistose because it does not contain flaky or fibrous minerals.

The ore of the Deer Isle mine consists of pyrite, chalcopyrite, zinc blend, magnetite, garnet, quartz hematite and other minerals. The sulphides and garnet occur as interlaminated, paper-thin sheets. The garnet is so highly crushed that it is nearly opaque when the nicols are not crossed. It is believed to be a regionally metamorphosed contact metamorphic deposit.

The deposits of the Milan Mine, N. H., are in most respects similar to those near Blue Hill. They are known to be regionally metamorphosed, since the ore body (as shown in Fig. 2, Pl. X.) has been faulted in the zone of flow for schist. The deposits before metamorphism, like those of Blue Hill, are believed to have been replacement veins in impure quartzite. Both are associated with intruding igneous rocks of acid composition which have since been regionally metamorphosed and the ores may be genetically related to them. The processes of metamorphism have obliterated such features as crustified banding and drusy cavities and have obscured evidences of hydrothermal metamorphism. Where such deposits are separated to form overlapping lenses, there is some evidence to show that they separate where the ore is most siliceous, for a mixture of sulphides and quartz seems to be less capable of resisting stresses under load than the more massive pyrite. In such cases a thin fissure with parallel schistosity will probably be found to connect the broken ends.

REVIEWS

The Iron Ores of the Iron Springs District in Southern Utah. By C. K. LEITH and E. C. HARDER. Bulletin 338, U. S. Geological Survey, 1908.

The iron industry in the United States has been hitherto almost entirely confined to the states lying east of the Mississippi River. St. Louis was indeed one of the earliest locations of an acid bessemer plant, but in later years situations nearer fuel supply have developed insuperable advantages. Pueblo, Col., maintains an important plant, and has been the sole large consumer of iron ores in the Rocky Mountain region. The Pacific coast has promise for the future, although little in the present. Alaska coke may some day make the converters possible. Yet iron ores west of the continental divide have for years attracted the attention of the prospector. The bodies in southwestern Utah, the subject of the excellent work before us, have become best known of all. They are not without possibilities of utilization; they are of more than usual geological interest; and they have been well and carefully studied.

The bulletin possesses several features which deserve special discussion and some other matter which can be more quickly summarized. The district is in southwestern Utah 250 miles from Salt Lake City and 22 miles from the nearest railroad, the San Pedro, Los Angeles and Salt Lake line which passes to the west. The sedimentary strata embrace the oldest formations of the region, and consist from below upwards of the Homestake Carboniferous limestone 50 to 500 feet thick with an average of 200; the Pinto Cretaceous sandstone, up to 3,500 feet but with an average of 1,000; the Claron Eocene limestone averaging 1,000 feet; a Pleistocene conglomerate 200 feet and less; finally later sands, gravels and clay bringing us to the present.

Two sets of igneous rocks are recognized; a series of Miocene intrusives, biotite-andesites in character, and a later series of effusive rhyolitic, trachytic and andesitic flows, tuffs and breccias. The intrusives have especially affected the Homestake limestone, and in the contact zones lie the chief ore-bodies, but others appear like dikes in the eruptive rock itself. The Claron limestone has also suffered, but to a less degree. It has been more seriously influenced by the effusives than by the intrusives.

The biotite andesite appears as three laccoliths in a northeast and southwest line. The southwestern one, called Iron Mountain, is roughly three miles by two miles and has ore bodies associated with the Homestake limestone on the southwestern and eastern borders, besides others within the eruptive area, especially surrounding an inclusion of the Pinto formation. Granite Mountain, the next laccolith, lies six miles northeast, is about two miles by a mile and a half in dimensions, and has ore bodies along the southern, eastern and northern contacts with the Homestake, and one smaller one in the Pinto. The third and largest laccolith, that of the Three Peaks, is a mile or two farther northeast and is mapped over an area four miles by two, much more remaining outside the map. The ores are found within the laccolith and in the contacts with the Homestake limestone on the south and west.

Some 1,600 exploration pits have been sunk upon the ores, and of these the deepest is 130 feet and is still above the water line. Estimated on the basis of superficial area and demonstrated depth, 40,000,000 tons of ore are indicated, but with a further allowance for depth much more would necessarily be included. As is usual in contact zones the iron minerals are both magnetite and hematite. While much of the ores runs above 60 per cent., the average is about 56. Phosphorus is uniformly high. Sulphur, copper and titanium are not in prohibitive amounts. The texture is hard and crystalline above, but, as is sometimes found in arid regions, the ores become relatively soft with depth. The gangue in the upper portions is quartz or chalcedony, and below there is more calcite. The contact minerals garnet, diopside, apatite, mica, hornblende and some others are minor constituents.

Besides the general topographic and geologic maps the bulletin contains individual geologic plans of the more important ore-bodies, and in the text are other sections, so that very excellent and complete illustrations are afforded.

The bulletin also contains a novel feature of more than usual interest to students of the chemistry of rocks. The authors have devised an ingenious plan of plotting a rock-analysis upon a circle in such a manner that the circle is divided into sectors whose areas are directly proportional to the percentages of oxides determined. This allotment of space is quickly made by dividing the circle at the outset into 100 sectors, each of which will correspond to one per cent. Percentages may then be rapidly plotted. Further than this, the original circle is divided into annular spaces by interior concentric circles so spaced that each annulus is equal to five per cent. of the total, but as we go outward the breadths of the successive annuli diminish. If now we desire to graphically express the changes from one rock already plotted

to another believed to be derived from it, as for instance from unchanged limestone to a contact zone, we can, after assuming some one ingredient to remain constant, place upon the diagram of the first a series of circles marking the proportionate parts of the second. Any marked or unusual change is thus graphically shown, and with the eye one can follow variations that would otherwise prove baffling because of complexity. The plan can, however, only be clearly grasped by close study of the text and diagrams and can be merely indicated here in its general outlines.

The origin of these ore-bodies is a point of more than ordinary interest. The first geologist to study and write of them, aside from brief and passing mention by the several surveys operating in this region was Dr. J. S. Newberry, who in 1880 had looked them over with care while reporting on the resources of western Utah for a proposed railroad. The good doctor had small faith in eruptive phenomena of any kind as developing ores, and all his old students later than 1880 will recall his annual citation of these Utah ores as the results of metamorphism from limonite, then the generally trusted method of formation for the magnetites of the Archean gneisses. Dr. Newberry states:[1] "The granite of the hills which contain the iron is finer grained and less compact than that which forms the great granitic axis of the Wasatch, and I suspect is the metamorphic condition of the quartzite beds which rest upon the Wasatch granite Some of the iron ore beds in this granite are distinctly interstratified with it, and are certainly, like it, metamorphosed sediments. This is plainly shown at the Blair Mine, where the principal crest of the hill is a distinct sheet of stratified, regularly bedded magnetite, from thirty to forty feet in thickness, dipping toward the north at an angle of about eighty degrees. Parallel with this principal layer are other sheets of magnetite separated by strata of granite, and varying from a quarter of an inch to ten feet in thickness, as perfectly parallel and regular as any series of sedimentary beds ever seen.

On the whole the Blair Mine is the most interesting and instructive outcrop of iron known to me, and furnishes the most striking proof of the sedimentary origin of these wonderful ore-beds. None of the other outcrops are so distinctly stratified, but the Big Blow-out at Iron City affords an equally conclusive argument against the eruptive theory; for while it appears to be a huge amorphous mass, like a hill of basalt, on examination it is found to be in large part composed of metamorphosed limonite; that is, magnetite, which has the botryoidal and concretionary aspect and radiated structure of limonite, and was

[1] *School of Mines Quarterly*, Nov., 1880, p. 11 and later, p. 12.

plainly deposited from water." Dr. Newberry evidently had in mind an intrusive origin for the ore, like a dike or a stock or a sheet, not the possibilities of contact metamorphism, and against this form of eruptive origin he brought his heaviest batteries to bear.

Later observers did not all fall in with these views, but although the deposits were often discussed informally among mining engineers, and although eruptive explanations found verbal expression, nothing definite appears to have been expressed until Professor Leith visited the region in 1903 and wrote a brief summary of the geological interpretation.[1] Professor Leith brought to the study of the deposits an exceptionally wide experience in the geology of iron ores and saw many features which failed to correspond to sedimentation. No bedding was visible; no clastic structure; there were steeply dipping tabular bodies but no folds; there were veins in the footwall andesite which was thus not granite; the largest bodies lay along the contact of andesite and limestone and swelled, pinched and disappeared along the strike. The conclusion reached was "that the ore is a secondary replacement and vein deposit, through the agency of percolating water, mainly along the contact of the andesite and limestone, but with veins extending into the footwall andesite and perhaps also into the overlying limestone." The possibility of original pyrite as a source of the ore was considered and the availability of the andesite and limestone as leachable materials upon the basis of known analyses was briefly expressed by a quantitative calculation.

At the Atlantic City meeting of the American Institute of Mining Engineers, February, 1904,[2] Mr. E. P. Jennings, of Salt Lake City, read a short paper on the "Origin of the Magnetic Iron Ores of Iron Co., Utah," which the authors of the bulletin apparently overlooked, as it is not cited. The present reviewer determined the rocks for Mr. Jennings and made a few microscopic observations on the ore. Mr. Jennings writes as follows (p. 341): "My conception of the origin of these magnetic iron ores is, that they are the result of an extreme basic differentiation from a basaltic magma in the deep; and, in a molten condition, they have been forced to the surface through fissures that were formed contemporaneously with the eruption of the magnetite, in a manner similar to the formation of basaltic and other eruptive dikes. When the quantity of material was more than sufficient to fill the fractures, it overflowed in the form of sheets. When the fractures extended into the overlying, sedimentary beds, they also have been filled

[1] Bulletin 225, U. S. Geol. Survey, 234–237, 1904. Also Bulletin 285, 199, 1906.

[2] *Transactions*, XXXV., 338–342, 1905.

with ore." As a preliminary test of the eruptive character the ore and wall-rock were studied with the microscope. "Professor Kemp . . . has determined the wall-rock to be diorite-porphyry. He has also examined thin sections of the ore for olivine, augite and plagioclase, with negative results. The sections examined by him showed considerable quartz, in the form of infiltrations. But, while these results are strongly against an eruptive origin for these ores, the evidence in the field is strongly in favor of it."

These three interpretations are strikingly in contrast and for this reason are of the greater interest. Upon our modern views there seems no way in which we can fall in with Dr. Newberry's explanation, but the results of careful study during the last ten years have shown a way to reconcile upon a common middle ground Professor Leith's percolating waters and Mr. Jennings's eruptive dikes and sheets, and that is contact metamorphism through the medium of heated magmatic waters or other vapors, fed by the laccoliths during their period of consolidation. This interpretation is the one followed by Professor Leith and Mr. Harder in the bulletin.

The contact metamorphism first produced a silicated zone not more than 60 feet wide, measured perpendicularly to the contact surface. The limestone contains varying amounts of albite, kaolin, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron ores, osteolite (*i. e.*, earthy apatite), andalusite, wollastonite, calcite, etc. These minerals occur in veins in breccias and disseminated throughout the rock. There are also local residues of a glassy base, apparently the wall rock fused by the heat of the intrusive mass. There are also places where the contact action only produced limonite-stained marble for a narrow belt. As was observed at San Jose, Tamaulipas, the magnetite has followed the formation of the silicates in time,[1] but the lime-silicates appear to be much less abundant in the Utah occurrence than they have been found in other places.

The bulletin gives two complete and five partial analyses of limestones representing the unaltered phase, and three of the normal contact phases. The two of the unaltered limestone have been averaged, plotted upon circles according to the methods outlined above and studied in conjunction with the normal contact effects. It is concluded by the authors that the silica and alumina maintain in the altered rock almost the same ratio to each other as in the unaltered. And since, if these two are assumed to be constant no very improbable inferences follow, with regard to the relations of other ingredients, whereas if any others are assumed to remain unchanged various improbabilities at once

[1] *Trans. Amer. Inst. Min. Eng.*, XXXVI., 195.

result, the further conclusion is reached that the contact zones have been formed, not by contributions of silica, alumina, etc., from the eruptive, but by the solution and removal of lime and magnesia from the limestone, leaving a residual product which was recrystallized into the silicate masses. Later the iron was yielded by the deep-seated portions of the eruptive, probably as ferrous chloride which reacts with water at temperatures above 500° C. as follows, yielding much heat.

$$3FeCl_2 + 4H_2O = Fe_3O_4 + 6HCl + H_2 + 77 \text{ calories.}$$

The free HCl is believed to be cared for by the limestone, leading to the replacement of the latter with magnetite. The physical conditions, the possibility of sodium coming in with the iron and many other interesting points are ably discussed by the authors, and cannot be followed out in greater detail here, but the question of the formation of the silicates whether by recrystallization of material indigenous to the limestones or whether by contributions of silica, etc., from the eruptive and the eviction of CO_2, is one of great scientific interest, and one which has been much discussed in later years. We may, therefore, state the evidence somewhat fully. The reviewer hopes that the authors of the bulletin will feel no hesitation in continuing the discussion even though authors sometimes are reluctant to reply to a review.

The analyses of the fresh and of the most significant altered limestones are as follows:

	Unaltered.		Normal Contact Phase.		
	A.	B	H.	I.	J.
SiO_2	8.08	6.90	50.73	52.00	57.05
Al_2O_3	1.95	1.03	14.63	9.32	9.86
Fe_2O_3	.87	1.04	11.51	5.08	3.10
FeO	.06	.75	1.13	2.41	1.80
MgO	2.86	4.52	6.36	9.40	8.16
CaO	46.67	47.15	1.24	14.47	8.61
Na_2O	.13	.13	2.02	1.94	4.30
K_2O	.77	.93	4.24	1.41	1.56
H_2O	1.01	1.04	7.03	3.30	3.89
P_2O_5	.05	.04	.32	.12	.13
CO_2	37.60	36.42	.21	.63	1.74
	100.05	99.95	99.42	100.08	100.20

A glance at the analyses brings out the great relative increase in silica and alumina, the moderate increase in iron, magnesia, soda, potash and water, and the great decrease in lime and carbon dioxide. The $SiO_2:Al_2O_3$ ratios are respectively A 4.14, B 6.7, H 3.47, I 5.6, J 5.8. Thcse range much the same in the two varieties of rock, although there

is enough difference to prevent one attaching undue importance to the figures. The ratios respectively of the SiO_2 in A to that in H, I and J are 6.28, 6.43 and 7.67. The ratios of the SiO_2 in B, respectively to that of H, I and J are 7.35, 7.54 and 8.27. These show the rate of increase on the possible combinations of analyses. In the same way the ratios of Al_2O_3, A to H, I and J run 7.5, 4.8 and 5.0; B to H, I and J 1.42, 9.0 and 9.6. These possible ratios of Al_2O_3 show a wide range, while the SiO_2 ratios are more even.

If we recast A and B for their mineralogical composition, we find reason to believe that they are not entirely unaffected by metamorphism. In neither is there sufficient CO_2 to satisfy the CaO and MgO as carbonates, and in order to provide for the excess of bases there seems no escape from concluding that wollastonite or diopside is present. Yet these two are not normally components of unaltered limestones. We usually find CO_2 sufficient to care for the alkaline earths and refer our SiO_2 to quartz, chert or kaolin. The unaltered limestones A and B are unusually high in K_2O and Na_2O so that on recasting we find these alkalies not unimportant constituents whether we calculate them as orthoclase and albite or as muscovite (sericite).

In columns A′ and B′ below are given the recast analyses from page 27 of the bulletin which correspond to A and B above and also under H′ and I′, those of H and I.

	A′.	B′.	H′.	I′
Calcite	78.30	72.40	.50	1.40
Magnesite ...	5.96	8.65	——	——
Kaolinite	4.90	2.58	24.77	11.61
Limonite	1.12	.56	3.74	1.31
Chert	2.64	——	18.78	1.50
Water	.16	.59	1.54	.81
Pyrite	.12	.84	——	——
Magnetite ...	——	.69	3.48	——
Wollastonite .	6.03	9.86	——	4.76
Enstatite	——	1.00	——	——
Actinolite	——	——	——	15.55
Diopside	——	——	2.16	20.52
Phlogopite ...	——	——	15.57	——
Serpentine ...	——	——	5.24	4.97
Andradite ...	——	——	——	11.20
Albite	——	——	16.77	16.24
Orthoclase ...	——	——	——	8.34
Hematite	——	——	5.92	——
Apatite	——	——	.62	.31
	99.23	97.17	99.09	98.52

These analyses give a very excellent idea of the general changes in metamorphism. The reviewer has rearranged the order slightly from the original so as to place together at the top those minerals presumably indigenous in sedimentary limestones and below those more characteristic of contact zones.

It was the reviewer's desire to test the probability of the author's conclusions regarding the lack of contributions from the eruptive in the following way. The analysis of the unaltered limestone A was recast anew because in the calculation of the minerals by the authors, K_2O and Na_2O were not used. Yet if we assign them respectively to orthoclase and albite, they involve between 5 and 6 per cent. of these minerals. The allotment of the necessary proportion of SiO_2 requires a slight rearrangement of several other minerals. The percentages in A were calculated as follows: The little FeO was assigned $FeCO_3$. Since there is not sufficient CO_2 to satisfy both MgO and CaO, the remaining CO_2 was divided between them proportionately to their molecular ratios. The excess MgO and CaO was assigned to diopside. Orthoclase and albite were next calculated and the excess Al_2O_3 used for kaolinite. The Fe_2O_3 gave the basis for limonite, and the remaining SiO_2 was called quartz and the H_2O, water. The composition given below under A″ then results. These percentages were then divided by the respective specific gravities of the several minerals, the quotients turned into per cents so as to get expressions for the volume percentages of each mineral. Taking next the mineral percentages as cited for H′ and I′ above, they were respectively divided by their specific gravities and volume percentages calculated as before.

A″ Revised Mineral Composition of A′.

	Sp. Gr.				Volume Per Cent.
Calcite	78.80	divided by 2.72	equals	29.0	or 79.3
Magnesite	5.12	divided by 3.33	equals	1.54	or 4.2
Siderite	.12	divided by 3.8	equals	.03	or .1
Kaolinite	2.32	divided by 2.5	equals	.93	or 2.5
Limonite	.93	divided by 3.8	equals	.25	or .7
Quartz	.30	divided by 2.65	equals	.11	or .3
Water	.56	divided by 1.	equals	.56	or 1.5
Diopside	5.87	divided by 2.9	equals	2.02	or 5.5
Orthoclase	4.49	divided by 2.55	equals	1.74	or 4.8
Albite	1.05	divided by 2.62	equals	.40	or 1.1
	99.56				100.0

Now, if the SiO_2 in the contact rock is the same actual SiO_2 that was in the unaltered limestone, having received no contributions, and

if from A to H the percentage becomes 6.28 times as much, and from A to I, 6.43 times as much, *i. e.*,

$$\left(\frac{50.73\ SiO_2 \text{ in H}}{8.08\ SiO_2 \text{ in A}} \text{ and } \frac{52.00\ SiO_2 \text{ in I}}{8.08\ SiO_2 \text{ in A}}\right),$$

then comparing equal weights of limestone and contact rock, we have to divide the latter's percentages by say 6 for a round number to make them correspond to the ingredients actually left as residues from the former. While this is not accurate for other ingredients than SiO_2, yet SiO_2 preponderates in the majority of the minerals concerned. The differences between the volume percentages both kinds of rock will give us an idea of what must have disappeared from the original limestone, expressed in volumes, in order to yield the contact rock. These are set side by side in the columns below and when expressed thus in volume loss, they stagger one's faith in the absence of the contributions from the eruptive.

	A.	H	Gain.	Loss.	A.	I.	Gain.	Loss
Calcite	79.3	.07	—	78.6	79.3	.2	—	79.1
Magnesite	4.2	—	—	4.2	4.2	—	—	4.2
Siderite	.1	—	—	.1	.1	—	—	.1
Kaolinite	2.5	3.8	1.3	—	2.5	2.0	—	.5
Limonite	.7	.4	—	.3	.7	1.5	.8	—
Quartz (chert)	.3	3.0	2.7	—	.3	.3	—	—
Water	1.5	.6	—	.9	1.5	.4	—	1.1
Magnetite	—	.3	.3	—	—	—	—	—
Wollastonite	—	—	—	—	—	.7	.7	—
Actinolite	—	—	—	—	—	2.3	2.3	—
Diopside	5.5	2.6	—	2.9	5.5	2.8	—	2.7
Phlogopite	—	2.2	2.2	—	—	—	—	—
Serpentine	—	.8	.8	—	—	.9	.9	—
Andradite	—	—	—	—	—	1.4	1.4	—
Albite	1.1	2.5	1.4	—	1.1	2.7	1.6	—
Orthoclase	4.8	—	—	4.8	4.8	1.4	—	3.4
Hematite	—	.5	.5	—	—	—	—	—
Apatite	—	.1	.1	—	—	—	—	—
	100.0		9.3	91.8	100.0		7.7	91.1
Net Loss				82.5				83.4

If this line of reasoning is justified, and as an approximation, it seems defensible, then in a contact zone 60 feet thick, we have the shrunken residue of a limestone belt about 300 feet thick and this seems hardly credible. As an alternative it would appear to involve less difficulties despite the significance of the ratios of SiO_2 and Al_2O_3 mentioned above, to believe that these and other ingredients had been fed

out by the cooling intrusive and that they had replaced the limestone in large part. The $CaCO_3$ then must have moved on elsewhere in solution in order to give place to them.

In the calculation only analysis A has been used but the results would not be essentially changed by using analysis B. The SiO_2 ratio was alone used, yet had the Al_2O_3 ratios been employed, ranging as they do from 4.8 to 14.2, they would have in the former case given a somewhat less amount of shrinkage, and in the latter case one more than twice as great.

Referring again to the ratios of the SiO_2 to the Al_2O_3 in the analyses A, B, H, I and J of 4.14, 6.7, 3.47, 5.6 and 5.8 respectively, it is interesting to note that the ratios of SiO_2 to Al_2O_3 in the five analyses of fresh andesite on page 49 of the bulletin are respectively 5.6, 4.0, 4.5, 4.5 and 4.0 which are much the same. It is also evident from these analyses that in three out of five analyses the K_2O exceeds the Na_2O. In one of the normal contact zones the same relation holds and in two the Na_2O is in excess. If we assume for a moment that in the early magmatic emissions the dissolved materials were something like the general composition of the laccolith, we would not have our test ratios in the unaltered limestone much affected.

In a word, it would seem to the reviewer that on the basis of the analyses there is still much reason to have confidence in emissions from the cooling eruptive as contributors to the substance of the contact zones.

J. F. KEMP.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

G. F. LOUGHLIN, J. A. ALLAN AND S. J. SCHOFIELD.

METALLIFEROUS DEPOSITS.

ALUMINUM.

I giacimenti bauxitici di Civita d'Antino e Balsorano (Abruzzo). By G. MARTELLI. Rass. Min. ecc. XXIX., 4 and 5, pp. 49–52 and 68–69. Torino, 1908.

Describes a bauxite deposit of good quality and economic value. (Geol. Zentralb., XIII., 1, 1909, p. 9.) L.

ANTIMONY.

The Auriferous Antimony Ore of West Gore, Nova Scotia. By D. F. HALEY. Eng. & Min. Jour. Vol. 88, No. 15, pp. 723–724, 1909.

Cites the occurrence of antimony in fissures, sometimes as lens-shaped pockets, cutting across the slates of lower Cambrian age which are better known as the "gold bearing series of Nova Scotia." The ore deposition is due to cold circulating waters. Deposition is still going on in vacated shafts. S.

CHROMIUM.

Les gisements de minerais de fer chromés en Grèce. By A. HABETS and N. BONANOS. Revue universelle des mines. T. XXI., 1908.

I. Les exploitations de la Société Hellénique des mines, pp. 129–138. Describes an interesting chromium-bearing oölitic iron ore of Greece. II. Notes sur les gîtes de minerais de fer chromés en Grèce, pp. 139–148. (Geol. Zentralb., XIII., 1, 1909, p. 7.) L.

COPPER.

Bergmännische Studienreise nach Angola. (Vortragsreferat.) By R. PILZ. II. Jahresber. d. Freiberger Geol. Ges. Pp. 15–18. Freiberg, 1909.

Short description of the mining and geological relations of the Portuguese colony of Angola. Mossamedes and Senze do Itombe are briefly described. At the latter place is a conglomerate richly impregnated with copper ores. (Geol. Zent., XIII., 2, p. 70.) L.

Die Kontaktmetamorphen Kupfererzlagerstätten von White Horse in Yukon (Kanada). By O. STUTZER. Zeit. f. prakt. Geol. Jg. XVII., 1909, H. 3, pp. 116–121.

Describes typical limestone contact deposits of magmatic origin, and gives the paragenesis of the minerals: pyroxene, magnetite, garnet, sulphides and amphibole, calcite. L.

Sulle ricerche minerarie nei giacimenti cupriferi del circondario di Alghero (Sassari). By A. STELLA. Rass. Min. ecc. XXIX., 14, pp. 212–213, Torino, 1908. (Italian abstract in Geol. Zent., XIII., 2, p. 71.) L.

The Miami-Inspiration Ore-Zone. By C. F. TOLMAN, JR. Min. & Sci. Press. Vol. 99, No. 20, pp. 646–650, 1909.

States that the ore body lies between a mass of granite and altered schists. The schist contains finely disseminated particles of chalcopyrite which has become leached out and concentrated on the contact by, supposedly, descending waters. A.

GOLD.

Gold Fields of Aurigao Peninsula, Mindanao, Filipinòs. By M. GOODMAN. Mining World. No. 20, Vol. XXXI., 1909, pp. 977–978.

Andesite is cut by stringers of quartz and calcite which contain gold. Gravel benches 100 feet above the creek have been washed which are derived from the disintegrated chloritic schist, into which the andesite has in places been altered. A.

Pye Valley Gold Mines, Oregon. By A. MATHEZ. Min. & Sci. Press. Vol. 99, No. 21, p. 687, 1909.

Briefly states that the gold occurs in a basalt dike between a limestone footwall and a granite hanging-wall. There is a quartz enrichment along the footwall and in it ore chimneys or shoots occur. The ore is free-milling to a depth of 200 feet. Below this it becomes associated with arsenopyrite. A.

Geology and Ore Deposits of Goldfield, Nevada. By F. L. RANSOME, assisted in the field by W. H. EMMONS and G. H. GARREY. U. S. G. S. Prof. Paper, No. 66, 1909, 251 pages, 34 figs. and 35 plates.

General geology, 106 pages; mineralogy, 27 pp.; economic geology, 65 pp. including 10 pages on the genesis of the ores; and the remaining pages contain mine descriptions.

The ore bodies are very frequently associated with siliceous volcanic rocks (dacites, etc.), are irregular in outline, and very rich. They

were formed near, probably within 1,000 feet of, the surface in early Tertiary times. Rich ore deposition is shown to be connected with alunitization. The hot siliceous mineral-bearing solutions came up along fissures and perhaps reached the surface in some places. Later fracturing of the rocks has caused renewed deposition. Three stages of deposition are recognized (p. 195). A.

IRON.

Extensive Iron Ore Deposits, Trondhjem, Norway. By H. H. SMITH. Min. Jl. Vol. LXXXVI., No. 3863, 1909, pp. 325–326.

States briefly that extensive masses of magnetite ore occur in hornblende and mica slate which is enclosed by granite. The ore occurs bedded in the slate in irregular lenticular masses. These iron fields are known by the name Follafoss-Storrfjield. A.

Parapara Iron-Ore Deposits. By J. M. BELL, Director of the Geol. Surv.; New Zealand. The New Zea. Min. Rec. Vol. XII., No. 10, pp. 441–446, 1909.

Describes at length the quality of the ore, the nature of the deposit and its extent. The ore is al ays hydrous iron-oxide, and occurs (1) as a replacement of the preëxisting carbonate rock or deposited directly from solution; (2) as conglomerate ores formed by the erosion of the replacement ores. The first is the more important. The writer believes it to have formed through the agency of bands of complex carbonates. Ferrous salt was carried in solution into the carbonate rocks, oxidized to ferric-oxide and deposited as limonite. A.

LEAD AND ZINC.

Ein neuerschlossenes Blei- und Zinkerzvorkommen in Tirol. By M. v. ISSER. Techn. Zentralb. f. Berg-, Hütten- u. Masch.-Bau. 19, No. 15, pp. 171–173.

Three sphalerite-galena veins in the Brixener granite. The gangue is quartz and feldspar. The ore forms 1/7 of the whole. (Geol. Zentralb., XIII., 1, 1909, p. 6.) L.

The Mine Hill and Sterling Hill Zinc Deposits of Sussex County, New Jersey. By A. C. SPENCER. Geol. Surv. of N. J. Ann. Rept. for 1908. Pp. 25–52. Trenton, N. J.

Contents: General description; development of the mines; the ore minerals and their occurrence; constitution of the ore; products of the mill; Mine Hill deposits; Sterling Hill deposit; characteristics and relationships of the zinc deposits; origin of the ores (introduced before or during metamorphic period, in part by partial replacement of limestone, and in part perhaps by bodily injection after the manner of igneous rocks). L.

MERCURY.

Le miniere di mercurio in Turchia. By F. P. MONACI. Rass. Min. ecc. XXVIII., 11, pp. 138–139. Torino, 1908.

A siliceous schist is impregnated with cinnabar in proximity to basalt. (Abstract in Italian in Geol. Zentralb., XIII., 1, 1909, p. 6.) L.

Dulces Nombres Quicksilver Deposit, Mexico. By P. A. BABB. Eng. and Min. Jour. Vol. 88, No. 14, pp. 684–686, 1909.

Cites these deposits as unique, in their origin and mode of occurrence, since they are different from any others yet described. The mercury occurs alone without any vein, gangue minerals or other economic minerals. The writer concludes that the mercury reached its present position as a gas, probably a pure mercury salt, in the form of a sublimate; and that this gas may have migrated from some distant deposit of the ordinary type. A.

Quicksilver at Huancavelica, Peru. By L. W. STRAUSS. Min. & Sci. Press. Vol. 99, No. 17, pp. 561–566, 1909.

Gives the history of the deposits which were first recognized in 1532. The cinnabar occurs as impregnations and irregular bunches in sandstone. It follows joint plains, covers the walls of cavities in limestone, and is sometimes found in conglomerate. The ore has been deposited from thermal solutions which have been caused to circulate by the intruded basalt and andesite in the district. A.

NON-METALLIFEROUS DEPOSITS.

ASBESTOS.

The Wyoming Asbestos Deposits and Mills. By A. LAKES. Min. Sci. Oct. 28, 1909, Vol. LX., No. 1552, p. 388–390.

The Laramie range consists of a granite core overlain by sedimentary rocks and penetrated by dykes of diorite and other igneous rocks, which are altered to serpentine and in this serpentine is the asbestos. The asbestos occurs in veins and narrow seams. The length of fiber is commonly within an inch.

CLAY.

Un giacimento di caolino nell' Agordino. By L. DE MARCHI. Estr. d. Atti e Mem. d. R. Acc. di Sci. XXIII., 4, pp. 1–6. Pavoda, 1907.

Describes alteration of a feldspathic schist into kaolin along a contact with pyrite, and attributes it to a pneumatolytic process. (Geol. Zent., XIII., 1, p. 9.) L.

GRAPHITE.

Graphite in the United States. By Dr. F. W. IHNE. Min. Sci. Vol. XL., Sept. 30 (pp. 297–298); Oct. 7 (pp. 316–318); Oct. 14 (pp. 343–346).

Reviews the graphite industry of the United States including the mineralogy and the geology of the different deposits in Pennsylvania, New York, New Jersey, Massachusetts, Alabama, Georgia, North Carolina, Virginia, Montana, South Dakota, Wyoming, California and Colorado. He also predicts a bright future for the graphite industry. S.

NITRATES.

Salpeterhaltiger Kalkstein im nördlichen Kaukasus als Rohstoff für die Herstellung von Kalkstickstoff. By M. GLASENAPP. Regasche Industriezeit. 1909, pp. 2–6.

General description, with analyses. The rock after subjection for a few days to dry winds, becomes encrusted with saltpeter. (Abstract in Geol. Zent., XIII., 3, p. 119.) L.

The Nitrate Deposits of Chili. By G. E. BROWN. Min. Jl. Vol. LXXXVI., No. 3862, 1909, pp. 259–263.

Four modes of occurrences are attributed to these deposits: (1) beds or lenticular deposits resting on loose detritus and covered with earthy conglomerates or very loose sand; (2) decomposed outcrop of eruptive rocks, cemented by sodium nitrate and other salts; (3) filled cavities in limestone rocks; (4) efflorescences on the surface of the dried lakes. The first of these is the only one of economic importance. The writer considers the nitrates to have been formed largely by the constant electrical discharges and the gases from active volcanoes that give rise to ammonia which, when it comes in contact with the common salt exposed on the upraised sea floor, would form sodium nitrate. The process of extraction is also described. A.

OIL AND GAS.

Die Entstehung der Erdöllagerstätten. By H. HÖFER. Petroleum. 4 Jg., 1908, No. 6. (Abstract in Geol. Zent., XII., 8, p. 547, 1909.) L.

Über Ansammlungen von Erdgas im Untergrunde Rigas. By B. Doss. Korresponzbl. d. Naturf.-ver. Riga. LI., 1908, pp. 47–53.

Gas derived from argillaceous sands rich in plant and mollusk remains. Composition: 87.5 per cent. CH_4, 5.4 CO_2, 1.4 CO, 4.7 N, 1.0 O. L.

Uber das Naturgasbohrlock auf dem Gute der Gebrüder Melnikow im Kreise Nowo-Usensk, Gouvernement Samara. By B. Doss. Ann. géol. et min. d. l. Russie. X., pp. 212–220, 1908. (In Russian and German.)

General description including analysis. (Abstract in Geol. Zentralb., XIII., 1, 1909, p. 8.) L.

Relations between Local Magnetic Disturbances and the Genesis of Petroleum. By G. F. BECKER. U. S. G. S. Bull. No. 401, pp. 24, 1909.

Cites the arguments for the organic and the inorganic origin of petroleum. The writer shows by means of a map that petroleum deposits are closely associated with magnetic disturbances, similar to those noticed about deposits of iron and nickel. He states in conclusion that such an association must be considered in discussing any petroleum deposit. Further investigation in this line is suggested.

A.

STONE.

The Slates of Arkansas. By A. H. PURDUE. Geol. Surv. of Arkansas, 1909, pp. 1–95.

Contents: Chap. I., Historic data relating to the slate industry; Chap. II., General considerations relating to slate; Chap. III., Geology of the Arkansas slate area; Chap. IV., Descriptions and tests of the Arkansas slates; Chap. V., Notes on quarries, prospects, and outcrops. L.

Building Stones of New Jersey. By J. V. LEWIS. Geol. Surv. of N. J. Ann. Rept. for 1908, pp. 55–124. Trenton, N. J.

Contents: The stone industry of N. J.; distribution of building stone in the state; granite and gneiss; trap rocks; sandstone and conglomerate; slate; limestone; marble and serpentine; resistance to fire; stone quarries of the state. L.

GLASS SAND.

The Deposits of Glass Sand at Toboso, Ohio. By F. CARNEY and A. M. BRUMBACK. Ohio Naturalist. Vol. 8, No. 7, pp. 358–361, 1908.

Describes the occurrence and preparation of a sandstone of Mississippian age for glass manufacture, and gives two analyses. L.

WATER.

Papers on the Conservation of Water Resources. Water Supply Paper, No. 234, U. S. G. S. P. 94, 1909. Reprinted from report of the Natural Conservation Commission, Feb., 1909.

Discusses the amount of rainfall, effect of floods and the present and future resources. Tables are given showing the amount of dissolved and suspended material being carried to the sea by the various drainage basins. The estimates show that the whole surface of the United States is being removed at a rate of 1 inch in 760 years. A.

ORE DEPOSITS.

Über Erzlagerstätten. By W. BRUHNS. Mitt. d. philomatischen ges. in Els. Lothr.

Discusses the most important ore deposits of Elsass-Lorraine. L.

Über Pegmatite und Erzinjektionen nebst einigen Bemerkungen über die Kieslagerstätten Sulitelma-Röros. By O. STUTZER. Zeit. f. prakt. Geol. XVII., 3, pp. 130–135, 1909.

The author verifies the gradation between pegmatites and ore veins, and describes the pyrite deposits as injection dikes. He also regards Broken Hill as an ore-injection. L.

Radioactivity of the Thermal Waters of Yellowstone National Park. By H. SCHLUNDT and R. B. MOORE. U. S. G. S. Bull. No. 395, p. 35, 1909.

This paper is not directly of economic importance but is nevertheless, worthy of note. The age of the deposits of travertine has been calculated from the radium content in them. There is a marked difference in the amount of activity in the various springs, the cold ones contain the higher percentage, while those with high temperatures do not retain the dissolved gases and have a low percentage. The writers consider the waters in these springs to have come through radium-bearing minerals in their underground flow. The disintegrated rock has a higher radium content than the rock from which it has been derived. A.

REGIONAL REPORTS.

Notes on the Mineral Industry of New Jersey, with Mineral Statistics. By H. B. KÜMMEL. Geol. Surv. of N. J. Ann. Rept. for 1908, pp. 125–146. Trenton, N. J.

Includes iron, zinc, copper, clay, stone, sand and gravel, Portland cement, lime, sand-lime brick, mineral waters, and greensand marl. Generally depressing conditions caused a decreased production in most of the products relative to 1907. L.

Die Lagerstätten nutzbarer Mineralien in der Schweiz. By W. HOTZ. Zeit. f. prakt. Geol. H. 1, 1909, pp. 29–42.

Short descriptions of occurrences of ores, asbestos, asphalt, petroleum, coal and salt. Asphalt and coal are the most important. L.

The Mineral Resources of the Philippine Islands, with a statement of the production of commercial mineral products during the year 1908. By W. D. SMITH and others.

Contents: Non-metallic minerals, by W. D. Smith; metallic minerals, by H. G. Ferguson; statistics by H. G. Ferguson; raw cement materials, by A. J. Cox; gold fields of Surigao Peninsula, Mindanao, by M. Goodman; production of structural material, by G. I. Adams. L.

Die Aussichten des Bergbaues in den Deutschen Kolonien (Vortragsreferat). By J. KUNTZ. II. Jahresber. d. Freiberger Geol. Ges. Pp. 25–27. Freiberg, 1909.

Short accounts of the most important mineral deposits. L.

Mineralvorkommen in Algier und Tunis. By B. SIMMERSBACK. Zeit. f. d. Berg-, Hutt.- u. Sal-wesen. Bd. 56, 1908, H. 5, pp. 595–604.

Short descriptions of iron, copper, zinc, and lead deposits. L.

Geologic Study of the Sierra of Guanajuato. Eng. & Min. Jour. Oct. 2, '09, Vol. 88, No. 14, pp. 672–677. Reviewed by editor.

The geology of the state of Guanajuato is reviewed. On the economic geology he summarizes as follows: "In regard to the classification of the deposits, it may be said that they are epigenetic primaries of Neocene age filling preëxisting cavities in fractured zones; they have the form of brecciated veins and are due to the circulation of ascending thermomineral waters; the deposits are argentiferous with an alloy of gold and they are encased in argillaceous schists and in diabasic and rhyolitic rocks. S.

A Geological Reconnaissance in Northern Idaho and Northwestern Montana. By F. C. CALKINS, with **Notes on the Economic Geology,** by D. F. MACDONALD. U. S. G. S. Bull. No. 384, p. 108.

General geology 91 pp.; economic deposits 17 pp. The principal ore is argentiferous galena which occurs chiefly in fissure veins. Some of these fissures lie relatively flat while others dip steeply. Deposits are more numerous where igneous intrusive rocks are more abundant, which reveals an intimate connection between ore deposition and igneous intrusion, which in this district is chiefly quartz-monzonite. A.

UNCLASSIFIED.

Bibliography of the Geology of Arkansas. By J. C. BRANNER. Geol. Surv. of Arkansas. 1909, pp. 97–164.

Gives authors, titles, and references of papers. L.

The Gases in Rocks. By R. T. CHAMBERLAIN. Jour. of Geol. XVII., 6, 1909, pp. 534–568.

Many gas analyses are classified in tables according to groups of rocks and minerals, ages of rocks, granularity of rocks. Gases chiefly are occluded or dissolved in rock, in part contained in cavities, and in part due to reactions. Relation between water and hydrogen is discussed, as are relations to vulcanism, to hypothesis of a molten earth and to the planetesimal hypothesis. While written to support the latter hypothesis the data may prove of value in connection with ore deposition. L.

The Solidification of Alloys and Magmas. By J. ASTON. Jour. Geol. XVII., 6, 1909, pp. 569–585.

Repeats explanations of cooling-curves and freezing-point-curves, and then compares the behavior of certain mineral groups with alloys in two and three component mixtures. Photomicrographs illustrate similarities in texture, and discusses the application of general laws of equilibrium to the study of igneous rocks. L.

La conquête minérale. By L. DE LAUNAY. Pp. 389. E. Flammarion, Paris, 1908. Price 3.50 francs.

A general consideration, in 16 chapters, of economic minerals, and its influence, past, present and future, on social and industrial conditions. L.

L' action des acides organiques en geologie. By L. W. COLLET. Arch. des Sc. phys. et nat. de Genève, T. XXV., pp. 70–72.

Emphasizes the importance of organic acids rather than of Carbonic anhydride in chemical erosion. L.

Cristallisation du quartz. By A. BRUN. Arch. des. Sc. phys. et nat. de Genève. T. XXV., pp. 610–611.

Quartz made to crystallize at 700–750° in presence of KCl and of NaCl vapors, proving that the presence of water is not necessary for the formation of quartz crystals. L.

Der Mensch und die Erde. Die Gewinnung und Verwertung der Schätze der Erde. Band V. **Die Beziehungen des Menschen zu den Mineralien von E. Harbort, J. Hart, Du Bois, and A. Miethe.** By H. KRAEMER. Deutsches Verlaghaus, Borg & Co. Berlin, 1908. Pp. 420, with 33 plates. Pr. 18 M. L.

Annual Report of the Ontario Bureau of Mines. T. W. GIBSON, Director. Vol. XVIII., pt. 1, 312 pages, 3 maps, 285 illustrations.

The work carried on by the Bureau is described; it includes a summary review of mining industry with statistical tables showing quantity and value of output. The iron ranges of New Ontario are described at some length by A. P. Coleman and E. S. Moore. S.

SCIENTIFIC NOTES AND NEWS[1]

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY. The legislature of 1909 appropriated $30,000 annually for the use of this survey. Of this sum $10,000 is a permanent appropriation, which the survey has received for several years. An appropriation of $10,000 for two years, chiefly for the use of the highway division, was repeated and a new appropriation of $10,000 annually for two years was granted for the establishment of a soil survey. The commissioners of the survey have appointed William O. Hotchkiss, formerly economic geologist of the survey, to the position of state geologist, and have placed the geological work of the survey under his immediate charge. For the present a considerable part of Mr. Hotchkiss's time is being given to the highway department, which has been under his direction.

SECRETARY CHARLES D. WALCOTT, of the Smithsonian Institution, has returned to Washington after a seven weeks' trip in the higher Canadian Rockies to the north and south of the main line of the Canadian Pacific Railroad. In continuation there of his geological work in the main range of the Rocky Mountains Mr. Walcott found the base of the great Cambrian System in a fossil sea-beach that now forms a bed of white quartz pebble conglomerate some 300 feet in thickness. Below this, 4,000 feet of limestone of an older period were measured, and above it over 12,000 feet of Cambrian limestones, sandstones and shales, in which fossils were found at many horizons. Large collections of rocks and fossils have been sent to the United States National Museum.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

PROFESSOR RALPH S. TARR, Cornell University, will spend the current year in Europe on sabbatical leave.

MR. H. I. STOEK, for many years editor of *Mines and Minerals,* has been appointed professor of mining engineering at the University of Illinois. He has recently been serving as an expert of the United States Geological Survey in charge of investigations of waste in mining anthracite. During the past three years he has lectured on mining at Cornell University, Pennsylvania State College, Sheffield Scientific School and Brooklyn Polytechnic Institute.

PROFESSOR JOSEPH P. IDDINGS is at present traveling along the east coast of Asia. In September he visited the southern part of Manchuria, making a study of certain Cambrian rocks there. He expected to visit Manila about Thanksgiving time, and while there would take occasion to see something of the volcanoes on the island of Luzon.

THE DEPARTMENTS OF GEOLOGY AND GEOGRAPHY at Cornell University have been reorganized and divided into five coördinate departments. These are geology, in charge of Professor Henry S. Williams, who is also director of the museum; physical geography, in charge of Professor Ralph S. Tarr; stratigraphic geology, in charge of Professor Gilbert D. Harris; economic geology, in charge of Professor Heinrich Ries, and mineralogy and petrography, in charge of Professor A. C. Gill. Professor Gill will also be chairman of the five departments.

THE UNITED STATES GEOLOGICAL SURVEY has for some time past been engaged in compiling maps of portions of the United States on the scale of 1 :1,000,000 in accordance with a plan which embodies the principal features on which agreement with other nations is expected. In view of the Geological Survey's interest in the results of the conference of several nations held in London, November 16, Bailey Willis, geologist, and S. J. Kübel, chief engraver, of the Survey, have been sent to London as representatives of the United States.

RALPH ARNOLD AND HARRY E. JOHNSON have resigned from the U. S. Geological Survey and taken up private practice in

Los Angeles as oil experts. Arnold's address is 726 H. W. Hellman Building, and Johnson is at 336 Byrne Building. Robert Anderson, who was Arnold's assistant for several years, carries on the survey's work in the California oil fields.

C. A. FISHER, of the U. S. Geological Survey, left Seattle for Katalla, Alaska, the middle of September to make an examination of the Cunningham coal claims for the Department of the Interior. He returned to Washington, November 8. The Cunningham case is now being tried in the Seattle land office.

GEORGE OTIS SMITH, director of the U. S. Geological Survey, spent part of the summer in geologic work in the High Sierras.

WALDEMAR LINDGREN is lecturing on economic geology at Massachusetts Institute of Technology this month.

W. J. REED, one of the younger geologists of the U. S. Geological Survey, died of typhoid fever in a Chicago hospital in September. He had spent the early part of the season in field work in Oklahoma.

JOSEPH A. TAFF, for many years geologist on the U. S. Geological Survey, resigned November 1 to become geologist to the Southern Pacific Railroad. He has moved his family to Palo Alto, California, and has an office in San Francisco.

COLGATE UNIVERSITY has conferred the honorary degree of doctor of science on Dr. John M. Clarke, state geologist of New York.

CHESTER W. WASHBURNE has gone to the Vera Cruz oil fields in Mexico for several months.

THE COAL LAND CLASSIFICATION BOARD of the U. S. Geological Survey working under the new schedule of valuation from April 9 to November 1, 1909, with the $300 maximum limit for the value of coal land per acre classified lands of a total value of $141,890,576. On the old basis of valuation this land would have been placed at $41,080,040. The month of July showed the greatest returns for any month under the new schedule. The work of the board in July included 695,456 acres valued at $63,248,379 or an average of $91 per acre, in contrast with a valuation under the old schedule of $13,525,000 at $20 per acre.

THE LARGE AND INTERESTING EXHIBIT which the U. S. Geological Survey installed in the Government Building at the Alaska-Yukon-Pacific exposition was taken to Chicago the latter part of October and set up in the Coloseum as a part of the display of the Land and Irrigation Congress, popularly known as the "Land Show." Mr. Robbins, who has been in constant attendance at the exhibit the past summer, reports that the Geological Survey exhibit is attracting a great deal of attention in Chicago and is proving most useful and instructive. The work shown is helping to convince the people at large of the indispensable character of the survey's activities and to place it among the most popular of the government bureaus.

MESSRS. MARSHALL, LEIGHTON AND MENDENHALL, of the U. S. Geological Survey, were in Hawaii a portion of the past summer to advise the territorial government in the inauguration of topographic and geologic work, which is to be done with special reference to water supply.

THE GEOLOGIC MAP OF NORTH AMERICA published by the Tenth International Geological Congress held in Mexico in 1907 is being revised for publication by the U. S. Geological Survey and has reached the stage where a preliminary draft is available for criticism. It can be seen by anyone interested at the office of the Geological Survey in Washington.

DURING DECEMBER Professor Gilbert D. Harris, State Geologist of Louisiana, will make an examination of Terre Bonne Parish, Louisiana, for the U. S. Geological Survey with special reference to the location of oil and gas pools. Professor Harris proposes to use and develop in this examination the magnetic method of locating oil and gas on which he has been working for several years.

MR. L. L. HUTCHISON, assistant director of the Oklahoma Geological Survey, spent the first year of his work with the survey in reviewing and confirming some of his earlier opinions on the oil fields. The field season just past was devoted to a study of the asphalt deposits of Oklahoma. He is now preparing a report on the asphalt and oil and gas of the state which,

when done, will probably be the most complete publication extant on Oklahoma asphalt, oil and gas.

PROFESSOR C. K. LEITH, of the University of Wisconsin, with two geologic assistants, spent the summer on the east coast of Hudson's Bay comparing conditions of pre-Cambrian sedimentation there with those of the Lake Superior region.

THE IRON ORES of the valleys of the Ottawa and Gatineau rivers have been the subject of an investigation by Mr. Fritz Cirkel, M.E., for the Mines Branch of the Department of Mines, and his report has just been published.

The publication of this report comes at an opportune time, owing to the development lately assumed by the smelting of iron ores by electricity; for the region in question possesses great water powers, a part of which could very aptly be applied to the establishment of an iron and steel industry.

Various iron ore deposits in the townships of Hull, Templeton, Wakefield, Bristol, Grenville and others are described in detail. Mr. Cirkel concludes that many of these would yield ores which could in all probability be treated profitably in the electric furnace. It is stated in the report that this method of reducing the iron ores can compete with the blast furnace for the production of pig iron, when electrical energy can be developed at a low cost.

All engineers and metallurgists interested in the iron and steel industry will read the report with interest, more especially the general conclusions, which are given from page 100 to page 107.

An appendix to the report gives a synopsis of the water powers, both developed and undeveloped, in the region under consideration. These data have been compiled from the latest authoritative sources available. The following falls can all be developed to produce large quantities of power: Paugan Falls; Cascades; Chelsea Rapids; Great Falls; Coulonge River; Roche Fendue; Calumet Falls; Chats Falls.

The report is illustrated and forms a volume of 147 pages. It is issued, under the direction of Dr. Eugene Haanel, by the Mines Branch of the Department of Mines.

AN INTERNATIONAL CONGRESS of mining, metallurgy, applied mechanics and practical geology will be held in Dusseldorf in Rhenish Westphalia, during the last week of June, 1910. The congress will be divided into four sections, Mining, Metallurgy, Applied Mechanics, and Practical Geology. By the payment of 20 Marks anyone so desiring can become a member of this congress and have the privilege of attending one section and receiving all publications that are issued by that section. Subscriptions are to be sent to the Stahlwerksverband, A. G., Dusseldorf, and endorsed "Congress of 1910." A card of membership will then be issued to all those who have made application and sent their remittance before March 1, 1910. In the Section of Practical Geology the following papers have been announced to date:

1. Importance of Practical Geology in Science and Political Economy.
2. Stratigraphy and Genesis of the Available Mineral Deposits. Calculations of their yearly output and resources.
3. Seismology, Terrestrial Magnetism, and Terrestrial Heat.
4. Questions Relating to Hydrology.
5. Utilization of Natural Resources of Water Power.

INDEX TO VOLUME IV.

[NOTE.—In this index the titles of principal papers and the headings of departments, as *Discussion*, are in italics.]

Abich, H., on oil in the Caucasus, 90; on the geology of Kertsch and Taman, 90
Accumulation of oil, 149, 512; diagrams of, 526; gravity theory of, 155; process of, 157, 519; structure a factor in, 156
Adularia, 634
Agalmatolite, 244
Aktchagil beds, 98
Alaskan tin deposits, Some features of the (Knopf)
Alberta, coal fields of (Dowling), 1
Albrecht, on cholesterol, 628
Allan, J. A., *Recent literature on economic geology*, 188, 283, 397, 580, 792
Altaite, 546
Alteration, of rocks, Hauraki gold field, 632; of sulphides to native silver, 316
Amphibole, 445
Analyses (*see* chemical analyses)
Anamorphism, zone of, 367
Anderson, on the origin of petroleum, 605
Andesite, 691, 699; analyses of, 637, 699
Andrusov, on the extent of the Neogene, 115; on the geology of Taman, 90
Ankerite, 211, 244
Anse La Britte, Louisiana, salt domes of, 27
Anthracite, of Wales, origin and distribution, 274
Anticlinal and hydraulic theories of oil and gas accumulation (Munn), 509
Anticlinal theory of oil and gas accumulation, Studies in the application of the (Munn), 141
Anticlinal theory of oil and gas accumulation, 147, 565
Anticlinals, in Galicia, 111; in Rumania, 106
Appalachian region, metallogenetic epochs of, 411
Apscheron Peninsula, geology of, 92
Apscheron stage, Pliocene, 91
Arid conditions, in the West, 35
Artesian basins, in southern California, 39
Artesian conditions along Gulf coast, 21
Asbestos, in Quebec, character of, 132; mode of occurrence, 137–138
Asbestos deposits, in Quebec, geology of, 130; map of 131
Asbestos deposits of the eastern townships of Quebec (Dresser), 130
Asbestos industry, in Quebec, extent of, 130
Asbestos mines, in Quebec, location of, 132
Asbestos veins, origin, 136; of Quebec, character of, 133
Ascending solutions, 314
Aspen, Colo., formations of, 301, 304; ore deposition at, 658
Aspen, Colorado, Ore-deposition at (Spurr), 301
Axinite, 218

Bacau oil districts, 104
Bachman Valley limonites, 535; analyses of, 535
Baicoi oil field, Rumania, 106
Bailey, J. T., on copper deposits of Adams County, Pa., 770
Bain, H. F., review by, 187
Baku and European oil-fields, a sketch of the geology of (Dalton), 89
Baku stage, Pliocene, 91
Balakhani series, Baku region, 94
Balakhani-Sabuntchi oil field, 96
Ball, S. H., on geologic column for southwestern Nevada, 712
Baltimore Co., Md., limonites, 536
Banket, 118; micro-sections of, 128
Barite, 49, 313
Barrosa Cota tin mine, 334
Bartonian, Eocene, 91
Basalt, De Beers mine, 441
Bastin, E. S., on metamorphism, 778
Batan Island, 229; coal of, 230

Bauxite, 49
Bayley, W. S., review of paper by, 265
Becker, G. F., discussion by, 373; on the Rand goldfield, 127; pebbles of, 126
Bedding faults, 302
Beketov, on the origin of petroleum, 606
Belly River coal formation, 9
Belly River formation, 2
Benger, W. G., on the Carpathian oil region, 115
Bertels, on the origin of Caucasian oil, 615
Berthelot, on the origin of hydrocarbons, 604
Bertrand and Renault, on the origin of petroleum, 616
Berzelius, on tellurium, 544
Bibliography, of Brewster iron district, N. Y., 754; Hauraki gold fields, New Zealand, 645
Bibliography of the diamond fields of South Africa (Julien), 453
Big Bonanza copper mine, Latouche Island, Alaska (Lincoln), 201
Big Bonanza mine, Alaska, 203; cost of mining, 204; development of, 206; geology of, 207; production, 207; ore-body, character of, 208
Big Bonanza ore-deposit, history of, 203
Bighorn area, coal, 6, 8
Binagadi oil field, Baku region, 97
Biot, on the optical properties of petroleum, 626
Biotite, 444, 447
Biotite dacite, 363
Bituminization of lignite, 611
Black Reef series, 120
Blairmore-Frank area, coal, 5, 6
Blue ground, analyses of, 449
Blue Hill, Maine, copper deposits, 759
Bog iron ores, 537
Bolivian tin deposits, The origin of (Rumbold), 321
Bonarowka beds, Oligocene, 109
Boryslaw-Tustanowice oil-field, 112
Boulder, from Calumet and Hecla conglomerate, 158
Brauner, on tellurium reactions, 533, 558
Braunite, 49
Breccia, 336, 698
Brewster iron-bearing district of New York (Koeberlin), 713; geologic map of, 714; geology of, 716; origin of ores, 748; bibliography, 754.
British Guiana, gold fields of, 490
Bronzite, 444, 446
Brougher dacite, 712
Brunet, on the formation of asphalt, 604
Buch, L. von, on the animal origin of petroleum, 613
Buck-quartz, 121
Buckley, E. R., discussion by, 175; review by, 178; discussion of review by, 258
Buehler, H. A., and Gottschalk, V. A., *Oxidation of sulphides*, 782–789
Burall, F. P., analysis by, 161
Burchard, E. F., review by, 571
Burdigalian, Miocene, 91, 102
Burgess, J. A., *The geology of the producing part of the Tonopah mining district*, 681–712
Butler, B. S., review by, 270
Byasson, on the origin of petroleum, 605

Calaverite, 545, 549, 552, 555
Calcite, 445, 448
Calcite andesite, 691; analysis, 692
Calcium sulphate, 25
California, southern, valley of, 37; ground water of, 38
Calkins, F. C., discussion by, 258; review by, 671
Cambrian limonites, 534
Cambrian rocks, Massachusetts, 241
Cambro-Ordovician limonites, 532
Campbell, M. R., review by, 71; discussion of review by, 261
Campeni oil field, 105
Capillary adhesion, 151
Capillary force, of water, 525
Carbonate ores, Appalachian region of Maryland, 537
Carroll Co., Md., limonites, 535
Cartersville, Ga., district, ores of, 49; mode of occurrence, 52; genesis of, 53
Cascade area, coal, 5, 7
Casin oil district, 105
Caspian beds, 90
Cassiterite, 215, 219
Castle Creek fault, 307
Cataricagua tin lode, 349
Caucasus, geology of, 89
Cave Spring district, Ga., ores of, 52
Cebu Island, 231; coal of, 232
Chalcocite, 212
Chalcopyrite, 209

Chemical analyses—andesite, 699; from Hauraki gold fields, 637; blue ground, De Beers mine, Kimberley, 449; boulder, from Lake Superior copper lodes, 160; calcite, 692; coal, 6–11, 234; from Philippine Islands, 234; dacite, Hauraki gold fields, 638; iron ore, 532–543, 741; from Cartersville district, 50; Keweenawan rocks, 161; manganese ore, 50; mine waters, 165; from Joplin district, 788; n'hangellite, 618; rhyolite, 690, 693; valencianite, 634
Chipman lode, 240
Chlorite, 447
Chloritoid, 122, 129
Cholesterol, 626, 629
Chrustschoff, on formation of garnet-rock, 365
Chrysotile, 135
Ciezkowic sandstones, Eocene, 110
Cirkel, F., review of work by, 661; on asbestos veins, 136
Claiborne stage, 16
Clapp, C. H., *Recent literature on economic geology*, 76
Clapp, C. H., and Ball, W. G., *The lead-silver deposits at Newburyport, Massachusetts, and their accompanying contact-zones*, 239–250
Clapp, F. G., discussion by, 565
Clark fault, 312
Clarke, F. W., on the constitution of minerals, 548; on transportation of gold, 561
Classification of auriferous deposits, 394; of coal, 653; of geologic materials, 646; of low grade coal, 262; of ore shoots, 61
Clay deposits, of Georgia, 573
Clay ironstone ore, analysis of, 537
Clay, associated with manganese ores, 53
Clay-working industry, history of, 667
Clinton iron ores, 538; analyses of, 539
Clinton ores, New York, 281
Coal, analyses of, 6–11, 234; anthracite, in Alberta, 9; classification of, 262, 653; Cretaceous, 1–11; Philippine Islands, 224; Chemical and physical properties of, 233
Coalfields, Philippine Islands, geology of, 228; map of, 225
Coal fields of Alberta (Dowling), 1
Coal measures iron ore, Maryland, 538
Coal mining, in the Philippines, history of, 227
Coal report, West Virginia, 71
Coal resources of the Philippine Islands (Smith), 224
Coals, of South Wales, 274
Cœur d'Alene district, Idaho, geology and ore deposits of, 178, 258
Coleman area, coal, 4, 6
Collier, A. J., discussion by, 262
Colorado, Georgetown quadrangle, economic geology of, 493
Coloradoite, 546
Colubyatnikov, D. V., on the oil region of Berekei, 90
Compostela-Danao coal field, Philippine Islands, stratigraphic column of, 229
Concordia mine, Bolivia, 323
Concordia tin lode, section of, 330
Conglomerate, gold-bearing, 118
Contact deposits, Garnet, of copper and the depths at which they are formed (Keyes), 365
Contact deposits, locus of formation, 365
Contact metamorphism, Alaska, 217
Contact minerals, Newburyport, Mass., origin of, 247
Contact zones, at Newburyport, Mass., 245
Coorongite, 618
Copper, Alaska, 201; in Lake Superior lodes, 158
Copper, Garnet contact deposits of, and the depths at which they are formed (Keyes), 365
Copper deposits, Adams Co., Pa., 770; Blue Hill, Maine, 759; Davis, Mass., 770; Ducktown, Tenn., 775; Ely, Vt., 769; Georgia, 774; Mason Valley district, Nev., 255; Newfoundland, 771; New Hampshire, 757, 768; Quebec, 771; Virgilina district, 772
Copper ores, experiments upon, 785; genesis of, 776
Cordilleran region, metallogenetic epochs of, 414
Corundum, 448
Costigan area, coal, 6, 8
Covellite, 212
Cox, A. J., on Philippine coal, 233
Coya tin mine, Bolivia, 332
Crane, W. R., review of work by, 67
Credner, on the origin of petroleum, 610
Crenulation, of mountain ranges, 421

Cretaceous, coal in, 2; of Galicia, 110; of Louisiana, 13
Criteria, for classification, 647, 652
Crookes, W., on diamonds, 452
Crosby, W. O., review by, 493
Crow's Nest coal field, 4
Crustal movements, in Louisiana, 17
Crystalline area of Georgia, 47; structure of, 48
Crystals, crushing of, 23; growing, power of, 23

Dacite, analyses of, 638
Dalmanites, 323
Dalton, L. V., *A sketch of the geology of the Baku and European oil-fields*, 89–117; *On the origin of petroleum*, 603–631; on bituminization of lignite, 611
Dana, J. D., on Brewster iron ore, 742, 747
Danburite, 220
Day, D. T., on filtration of petroleum, 630; on pyrite in placer sands, 377
De Beers mine, peridotite of, 438; rocks in shaft, 440, 441
Decay, residual, 51
Decomposition of a boulder in the Calumet and Hecla conglomerate, 158
Definition, of marl, 485
De Launay, on metalliferous veins, 366
Deleasse, on nitrogen in Trinidad pitch, 609
Denny, G. A., discussion by, 470
Depth, of fissures, 430; of saturated solutions of salt at varying temperatures, 22
Descending waters, work of, 315
De Smet, on coal on Red Deer River, 1
Devereux, W. B., on gold in Dakota, 123
Devonian limonite ore, 531
Deweylite, 447
Diagrams—accumulation of oil, 526; alteration of rocks, Hauraki gold fields, 640; asbestos pit at Black Lake, Quebec, 133; Calumet and Hecla conglomerate, outcrop, 172; Concordia tin lode, 324, 326, 328, 330; dome growth, 24; folding in Carpathians, 104; fracturing, 429; olivine serpentinized, 135; orebody in Nevada, 174; Petit Anse Island, model of, 27; Rand conglomerate, 128; salt in saturated solutions at various temperatures and depths, 22; saturated solutions of sodium chloride, at varying temperatures, 22; schistose structure, 332; serpentine, altered from peridotite, 134; solubility of gypsum in salt, 25; tin-bearing dike, New South Wales, 325; vein system, Tonopah mining district, 702; water levels in southern California wells, 42
Diamond, formation of, 452
Diamond-bearing peridotite of Kimberley, South Africa, Petrographic note on the (Hartog), 438
Diamond fields of South Africa, A bibliography of (Julien), 453
Diamond mines, South Africa, 439
Dickson, G. H., analysis of coal by, 6
Dike, rhyolite, at Tonopah, 690
Dinagat Island, coal of, 233
Diopside, 243, 444
Diorite, 243, 733
Diorite porphyry, 301, 305
Discussion—
Classification of geologic materials (Grout), 646
Classification of low grade coal (Collier), 262; (Grout), 653
Definition of marl (Stewart), 485
Geology and ore deposits of the Cœur d'Alene district (Calkins), 258
Lead and zinc mining in the Central States in 1907 (Buckley), 175
Localization of values in orebodies and the occurrence of shoots in metalliferous deposits (Lindgren), 56; (Lane), 158; (Chase), 173; (Jennings), 255
Ore-deposition at Aspen, Colo. (Loughlin), 658
Origin of the gold in the Rand gold field (Hellmann), 251; (Becker), 373; (Denny), 470
Studies in the application of the anticlinal theory of oil and gas accumulation (Clapp), 570
West Virginia Geological Survey (White), 261
Displacement phenomena, 428
Dobrotow beds, Oligocene, 109
Dolcoath lode, 220
Dolomite, 445
Dome alignment, Louisiana, 19

Dome structure, modification of, 27
Domes, complexity of structure explained, 26; rate of growth, determination of, 33; salt, 15; of foreign countries, 30; structural, 21; growth of, 24; origin of, 21
Doming, in Aspen district, Colo., 308
Don, J. R., on the origin of the gold ores of Hauraki, 644
Dowling, D. B., *The coal fields of Alberta*, 1–11
Drake's saline, Louisiana, section of, 27
Dresser, John A., *On the asbestos deposits of the eastern townships of Quebec*, 130–140
Durdenite, 546

Eastlake, A. W., on petroleum in eastern Europe, 115
Economic geology, recent literature on (Loughlin and Clapp), 76; (Loughlin and Allan), 188, 283, 397, 580, 792
Edmonton coal, 11
Edmonton formation, 2, 10
Elisa tin lode, section of, 331
Elk River Valley, coal formation of, 4
Ells, R. W., on asbestos veins, 136; on ore deposits in Quebec, 771
Elsass oil-fields, 116
Ely, Vt., copper deposits, 769
Emerson, B. K., on Davis copper ores, 770
Emmons, S. F., review by, 67
Emmons, W. H., *Some regionally metamorphosed ore deposits and so-called segregated veins*, 755–781
Emmonsite, 546
Engler, on the distillation of fish oil, 614; of mud, 620; on the formation of petroleum, 612, 625; on the optical properties of petroleum, 628
Eocene, Baku region, 91; Galicia, 110; Louisiana, 15; Rumania, 102
Exaltacion tin lode, 351

Faulschlamm, 621
Fault zones, Louisiana, 19
Faulting, at Aspen, Colo., 302, 306; in Concordia tin lode, Bolivia, 329; in Georgia, 48; in the Sierra Madre Oriental mountains, 425; in the Tonopah mining district, 701, 709
Faults, at Balcones and Red River, 30; in Louisiana, 19
Features, Some, of the Alaskan tin deposits (Knopf), 214
Fenneman, N. M., on the occurrence of salt, 26
Ferine shale, 2
Ferrotellurite, 546
Finlayson, A. M., *Problems in the geology of the Hauraki gold fields, New Zealand*, 632–645
Fischer, N. W., on the action of tellurium, 550
Fissures, 422; depth of, 430
Five Islands, Louisiana, 12
Florida State Geological Survey, First annual report, 186
Fluorspar deposits, of Kentucky, 571
Fohs, F. J., review of report by, 571
Folding, at Aspen, Colo., 302, 306; in Baku oil district, 95; in the Carpathians, 104; in Galicia, 111; in Georgia, 48; in the Tonopah mining district, 709; in the Sierra Madre Oriental mountains, 427
Folding of rock strata, Some phenomena of the (Nason), 421
Forces repelling movement of oil, 151
Fordham gneiss, New York, 716
Forsyth, R. O., analysis by, 165
Fossils, of Jackson age, occurrence of, 16; of Philippine coal fields, 229
Fraas, on the origin of petroleum, 614
Fraction dacite breccia, Tonopah, 704
Fractures, resulting from thrust, 429
Frederick Co., Md., limonites, 535
Friedlander, on diamonds, 452
Fritsch, on algal growth, 621

Galena, 211, 240, 244
Galicia, physiography of, 108; geologic map of, 109; geologic series of, 109; oil of, origin of, 110; oil fields of, 111
Gallofa tin lode, 334
Garnet, 243, 444, 447
Garnet contact deposits of copper and the depths at which they are formed (Keyes), 365
Garnetization, 372
Garnet-rock, formation of, 365
Gas, occurrence in domes, 25
Gas accumulation, Studies in the application of the anticlinal theory of oil and (Munn), 141
Gas accumulation, The anticlinal theories of oil and (Munn), 509

Geikie, A., on pyrite, 376
Genth, on montanite, 546
Geologic history, of Tonopah mining district, 711
Geologic maps—Alberta coal fields, 3; Apscheron Peninsula, 92; Brewster iron-bearing district, N. Y., 714; Galicia, 109; Louisiana and southeast Texas, 13; Negro Pabellon tin district, 347; Rumania, 100; Tonopah mining district, 681; Transvaal, 471 (*see also* Maps)
Geologic materials, classification of, 646
Geological occurrence of rock salt in Louisiana and east Texas (Harris), 12
Geology of, Alaskan tin deposits, 216; Apscheron Peninsula, 92; Baku and European oil-fields, 89; Brewster iron district, N. Y., 716; Latouche Island, Alaska, 207; Newburyport, Mass., lead-silver deposits, 241; Philippine Islands coal fields, 228; Rumania, 102; Tres Cruces tin field, Bolivia, 322
Geology of the Baku and European oil-fields, A sketch of the (Dalton), 89
Geology of the Hauraki gold fields, New Zealand, Problems in the (Finlayson), 632
Geology of the producing part of the Tonopah mining district (Burgess), 681
Georgetown district, Colo., 317
Georgia, clay deposits of, 573
Georgia, The manganese ore-deposits of (Watson), 46
Gneiss, 716
Gold, association with tellurium, 547; geologic occurrence and geographic distribution, 391; reactions with selenium, 551; with tellurium, 550; solution and precipitation of, 122, 562, 563
Gold, of the Rand, distribution of, 123, 126, 251
Gold of the Rand goldfield, The origin of the (Gregory), 118
Gold ores, of the Rand, microscopic structure of, 127–129
Gold and silver, treatise on, 67
Gold fields, of British Guiana, geology of, 490
Golubiatnikov, on Palæogene deposits of Baku, 94
Goodchild, on pseudomorphs, 167
Gossan, at Big Bonanza mine, Alaska, 212
Grand Gulf sandstones, 17
Granite, 243; at De Beers mine, 441; at Thetford, origin of, 139
Granite stocks, intrusive, 216
Granitic gneiss, 722
Graphite, 661
Graton, L. C., on Virgilina copper ores, 773
Gregory, John W., *The origin of the gold of the Rand goldfield*, 118–129; on sections of the New Goch mine, 126
Griffiths, on the origin of petroleum, 609
Griswold, W. T., on accumulation of oil, 514; on the anticlinal theory, 147
Ground water, fluctuations of, 43
Ground water problems in the West, A phase of (Mendenhall), 35
Grout, F. F., discussions by, 646, 653; on the oxidation of pyrite, 782
Grozni oil region, 98
Grzybowski, on Foraminifera of oil-sands of Krosno district, 110; on the geology of Boryslaw, 112
Gunnison formation, Colorado, 305
Gypsum, 25; occurrence in domes, 25

Handbook for field geologists, 667
Hanover, oil in, 117
Harford Co., Md., limonites, 536
Harger, H. S., on diamonds, 452
Harris, G. D., *The geological occurrence of rock salt in Louisiana and east Texas*, 12–34
Harrison, J. B., review of work by, 490
Hartog, v., *Petrographic note on the diamond-bearing peridotite of Kimberley, South Africa*, 438–453
Hatch and Corstorphine, on origin of Rand ores, 121
Hauraki gold fields, New Zealand, Problems in the geology of the (Finlayson), 632
Hayes, C. W., review of work by, 667
Heat phenomena, causes of, 432
Heath, G. L., analysis by, 165
Hector, J., on coal on the Souris River, 1
Heller dacite, Tonopah, 704
Hellmann, F., discussion by, 251
Helvetian, Miocene, 91, 102
Hematite, 49
Hematite ores, Maryland, 538

Henderson, C. H., on copper deposits of Adams County, Pa., 770
Henrich, C., on Ducktown ores, 775
Hess, F. L., reviews by, 577, 661
Hessite, 546, 549, 552
Hice, R. R., review by 667
Hille, F., review of report by, 575
History of, Big Bonanza ore-deposit, 203; clay-working industry, 667; coal mining in the Philippines, 227; discovery of coal in Alberta, 1; iron industry of Maryland, 530; lead-silver mining at Newburyport, Mass., 239; tellurium, 544
Hitchcock, C., on the genesis of Gardner Mountain deposits, 757, 768
Höfer, on the origin of petroleum, 614
Holden, R. J., review by, 281
Holland, T. H., review of paper by, 270
Hornblende granite, 131
Huanuni tin district, 349
Hulsite, 218
Hundred-foot sand, distribution of, 144; section of, 145
Hunt, R., on segregation veins, 757
Hunt, T. S., on Ducktown ores, 775; on mineral waters, 166
Hutton, F. W., on the origin of the gold ores of Hauraki, 644
Hydraulic theory, of oil accumulation, 518
Hydraulic, The anticlinal and, theories of oil and gas accumulation (Munn), 509

Ilmenite, 447
Impregnation theory of origin of Rand gold ores, 121, 129
India, mineral resources of, 270
Infiltration theory, of origin of Rand gold, 122, 471
Inliers, of Cretaceous, 14
Inorganic origin of petroleum, theory of, 604; geologic arguments for, 606
Intrusions, Alaska, 217; Brewster district, N. Y., 733
Intrusive rocks, Aspen, Colo., 305
Inwood limestone, New York, 728
Ionic circulation, 168
Iron ore, analyses of, 50, 534, 741, 745; limestone contact deposits, 533; micro-sections of, 739, 744; residual deposits of, 534
Iron ores, epochs of, 413; of Brewster district, N. Y., 738; of Ontario, 575; of southern Utah, 790
Iron ores of Maryland (Singewald), 530; map showing distribution, 530
Iron oxides, 447
Iron-bearing district of New York, The Brewster (Koeberlin), 713
Irrigation, in southern California, 40
Irving, J. D., on gold in Dakota, 123

Jackson stage, 16
Jahn, on the origin of petroleum, 615
Jamna sandstone, Cretaceous, 110
Jennings, E. P., discussion by, 255
Jeremejew, R. W., on pyrite in placer sands, 379
Jimenez copper deposits, Mexico, 366; section of, 371
Johnson, J. P., review of paper by, 577
Jones, T. R., on the composition of asphalt, 609
Joseite, 546
Judith River formation, 2
Julien, A. A., *A bibliography of the diamond fields of South Africa*, 453–469; on pyrite, 376
Jurassic, Mexico, 423

Kalgoorlite, 546
Kemp, J. F., reviews by, 273, 790; on Ducktown ores, 775; on the genesis of certain ore deposits, 757
Kentucky, fluorspar deposits of, 571
Keweenawan rocks, analyses of, 161
Keyes, C. R., *Garnet contact deposits of copper and the depths at which they are formed*, 365–372
Kharitchkov, on the animal origin of petroleum, 615
Killas, 216
Kimberley, peridotite from, 438
Kimberley, South Africa, Petrographic note on the diamond-bearing peridotite of (Hartog), 438
Kimberlite, 451
Kinetic friction, 151
Kirschbaum, L., analysis by, 161
Klaproth, on tellurium, 544
Knab, on the origin of bitumens, 614
Knapp, I. N., on anticline in Louisiana, 20
Knopf, A., *Some features of the Alaskan tin deposits*, 214–223
Knox dolomite, decay from, 51
Koeberlin, F. R., *The Brewster iron-bearing district of New York*, 713–754
Kokscharow, N. von, on pyrite in placer sands, 379
Konschin, A. M., on oil-fields of the

Trans-Kuban province, 90; on the structure of the Balakhani oil-field, 96
Kootanie formation, 2–4
Krämer and Böttcher, on polymerisation, 630
Krämer and Spilker, on the origin of petroleum, 617
Krennerite, 545, 549, 554, 555
Krosno oil-field, 115; section in, 114
Krusch, P., review of work by, 65; on denudation, 367

Lafayette formation, 536
Lane, A. C., discussion by, 158
Larsen, E. S., on rhyolite, 689
Latouche Island, Alaska, 201–203; view of, 203
Lawson, A. C., review by, 667
Lead, in Central States, 175
Lead and zinc deposits, origin, 413; of Aspen, Colo., 314
Lead-silver deposits at Newburyport, Massachusetts and their accompanying contact-zones (Clapp and Ball), 239
Leith, C. K., reviews by, 265, 385; on rock cleavage, 777
Leith, C. K., and Harder, E. C., review of work by, 790
Lemière, on bacterial action, 624
Lenher, V., *Some observations on the tellurides*, 544–564
Lenz, on the optical properties of white naptha, 626
Lesquereux, on fucoids in the coal measures, 610; on the vegetable origin of Pennsylvania oils, 616
Leucoxene, 634
Levantine, Pliocene, 102
Lewis, H. N., on kimberlite, 451
Lewkowitsch, on cholesterol, 627
Lignite, in Alberta, 1–11
Limestone, microscopic section of, 719
Limonite, 49; analyses of, 532–543
Limonite ore, Maryland, 531; Devonian, 531
Lincoln, F. C., *The Big Bonanza copper mine, Latouche Island, Alaska*, 201–213
Lindgren, W., *Metallogenetic epochs*, 409–420; discussion by, 56, 62; review by, 65; on chlorite, 780; on diamonds, 452; on metasomatism, 636; on ore deposition, 249; on the formation of garnet, 762; on the origin of Hauraki gold ores, 641; on valencianite, 634
Lines, E. F., review by, 573
Literature on economic geology, Recent (*see* Recent literature etc.)
Livingston area, coal, 5, 6
Llallagua tin district, 352
Lode-tin deposits, Alaska, 219
Londinian, Eocene, 91
Los Angeles, water supply of, 36, 45
Loudon formation, magnetites in, 541
Loughlin, G. F., *Recent literature on economic geology*, 76, 188, 283, 397, 580, 792; discussion by, 658
Louis, H., on the origin of the Rand gold, 119
Louis and Phillips, on Bolivian tin deposits, 321
Louisiana, geologic formations of, 13; rock salt in, 12
Louisiana and east Texas, The geological occurrence of rock salt in (Harris), 12
Low, A. P., on asbestos veins, 136
Lower Mississippi region, structure of, 19
Lucas, A. F., on salt islands of Louisiana, 12
Lucas copper deposits, New Mexico, 366
Luizi, W., on diamonds, 452

Mackenzie, A., on the occurrence of coal on Great Bear River, 1
Maclaren, J. M., review of work by, 391
Mæotic, Miocene, 91, 102
Magmas, types of metals in, 419
Magnetite, 447
Magnetite ores, of Maryland, 541; analyses of, 542; in schistose rocks, 542; in serpentine, 543; of New Jersey, 265; of Pennsylvania, 385
Magura sandstone, Oligocene, 109
Main Reef Leader, of Rand gold field, 125
Malachite, 212
Manganese-ore, analyses of, 50; mineral forms of 49; mode of occurrence, 52; genesis of, 53; production of, 55
Manganese ore-deposits of Georgia (Watson), 46
Manganite, 49
Manhattan schist, New York, 730
Manto, 346, 348, 431; formation of, 436
Maps—Alberta, coal fields, 3; artesian basins in southern California, 39; Bolivian tin deposits, 323; Eu-

rasian oil districts, 89; Maryland iron ores, 530; oil pools of Sewickley quadrangle, Pa., 143; Philippine Islands coal fields, 225; Prince William Sound region, Alaska, 202; Price's saline, north Louisiana, 14; Quebec, eastern townships, 131; Rhang-el-Melah, Algeria, 32 (*see also* Geologic maps)
Marble, 247
Marcusson, on the optical properties of petroleum, 627
Marl, definition of, 485
Maroon formation, Colorado, 305
Maros Valley, Hungary, section of, 29; salt mine, 30
Maryland, The iron ores of (Singewald), 530
Materials, geologic, classification of, 646
Mather, W. W., on Brewster iron ore, 746, 747
Melonite, 546
Mendeliéeff, on the origin of petroleum, 605
Mendenhall, W. C., *A phase of ground water problems in the West*, 35–45
Menilite shales, Oligocene, 105, 110
Merrill, G. P., on asbestos veins, 135
Mesozoic epochs, of ore deposition, 415
Metallogenetic epochs (Lindgren), 409
Metamorphism, 435; in Alaska, 217
Metamorphosed ore deposits and so-called segregated veins, Some regionally (Emmons), 755
Metasomatic replacement, 248
Mexico, geological section of the Sierra Madre Oriental, 424, 426
Meyer, on the occurrence of petroleum, 624
Mica andesite, 362
Microscopic sections, of Rand conglomerate, 128; of serpentine altered from peridotite, 134
Midway beds, 15
Mikhailovski, on origin of Caucasian oils, 92
Milan mine, New Hampshire, 762; genesis of ore, 767
Mine waters, 165; analyses of, 165; of Joplin district, analyses of, 788
Mineral deposition, 423
Mineral resources, of India, 270; of Virginia, 386
Mineralogy, optical, 671
Mining costs, Big Bonanza mine, 204
Miocene, Baku region, 91; Galicia, 109; Louisiana, 17; Rumania, 102
Mississippi embayment, extent of, 16
Mississippi, lower, course of, 20
Mississippi, lower, region, structure of, 19
Missouri lead and zinc deposits, 175
Mizpah fault, Tonopah, 709
Moinesti fold, 105
Molecular cohesion, 151
Molecular repulsion of oil and water, 151
Molengraaf, G. A., on kimberlite, 452
Monroe, H. S., on Brewster iron ore, 742
Montanite, 546
Monte Blanco tin mine, 333
Moose Mountain area, coal, 5, 7
Mora sandstones, New Mexico, 369
Morgan, on the origin of Hauraki gold ores, 642
Morgan, P. G., on zeolites, 635
Morgan and Tallmon, on bitumen in a fossil egg, 615
Morococala tin district, 350
Morrey, C. B., on fossil bacteria in oil rocks, 624
Mt. Ararat, Tonopah, view of, 706
Mt. Brougher, Tonopah, view of, 708
Movement, of oil in porous rocks, 148, 514; of rocks, 429
Movements, in Carpathians, 104
Mrazec, on oil in the Bacau district, 105
Müller von Reichenstein on tellurium, 544
Munn, M. J., *Studies in the application of the anticlinal theory of oil and gas accumulation*, 141–157; *The anticlinal and hydraulic theories of oil and gas accumulation*, 509–529
Murchison, R., on the bituminization of schist, 613
Murgoci, G. M., on the origin of oil in Rumania, 103
Muscovite, 447

Nagyagite, 546, 552
Nason, F. L., *Some phenomena of the folding of rock strata*, 421–437
Natterer, on the occurrence of petroleum, 620
Negro Pabellon tin field, 344; geologic map and section of, 347
Neuberger, on the animal origin of petroleum, 615
Nevada, Tonopah mining district, 681

Newberry, on the vegetable origin of petroleum, 616
Newburyport, Mass., lead-silver deposits, 239
New Jersey, magnetite and zinc ores, 265
New Hampshire, Milan copper deposits, 762; genesis of, 767; Ammonoosuc district, 768
Newland, D. H., and Hartnagel, C. A., review of paper by, 281
New Mexico, copper deposits, 366; sequence of rock formations, 368
New York, Clinton ores, 281
New York, The Brewster iron-bearing district of (Koeberlin) 713
New Zealand, Hauraki gold fields, Problems in the geology of the (Finlayson), 632
N'hangellite, 618; analysis of, 619
Notes and News, Scientific (*see* Scientific notes and news)
Nuevo Leon, Mexico, geological section in, 424, 426

Observations, Some, on the tellurides (Lenher), 544
Ocher, 49
Oddie rhyolite, 712
Oil, movement in porous rocks, 148, 150; origin of, 510, 519; organic theory of origin of, 511; places of accumulation, 149; occurrence in domes, 25; in the Baku field, 89; in the Carpathians, 104; in the Sewickley quadrangle, Pa., 142
Oil pools, 20; in Sewickley quadrangle, Pa., map of, 143
Oil sands, Pa., 142
Oil and gas accumulation, factors of, 513
Oil and gas accumulation, Studies in the application of the anticlinal theory of (Munn), 141
Oil and gas accumulation, The anticlinal and hydraulic theories of (Munn), 509
Oil-fields, Baku and European, A sketch of the geology of (Dalton), 89
Oligocene, Baku region, 91; Galicia, 109; Louisiana, 16; Rumania, 102
Olivine, 445
Olivine serpentinized, figure of, 135
On the origin of petroleum (Dalton), 603
Ontario, iron ore deposits of, 575
Optical mineralogy, 671
Ore deposition, epochs of, 411
Ore-deposition at Aspen, Colorado (Spurr), 301; sequence of, 318
Ore deposits, 273, 409–420; examination and valuation of, 65; metamorphosed, 756; of Aspen, Colo., 311, 658; of South Africa, 577
Ore-deposits, manganese, of Georgia (Watson), 46
Ore shoots, 56; in Nevada, 173; of Hauraki gold fields, 641
Origin of, asbestos veins, 136; contact minerals, Newburyport, Mass., 247; copper ores, 776; of Milan, N. H., 767; domes, salt, 21; gold deposits, Hauraki, New Zealand, 641; of the Rand, 118, 251; granite of Thetford, Quebec, 139; iron ores, Brewster district, N. Y., 748; lead and zinc deposits, 413; lead-silver deposits, Newburyport, Mass., 239; manganese ores, of Georgia, 53; oil, 510; of Galicia, 110; of Rumania, 103; ore deposits, 409–420; at Aspen, Colo., 311; pebble-reef of the Rand, 118; petroleum, 603; rock salt, 12; saline solutions, 28; salt deposits of New York-Ontario area, 33; zinc and lead deposits, 413
Origin of petroleum, On the (Dalton), 603
Origin of the Bolivian tin deposits (Rumbold), 321
Origin of the gold of the Rand goldfield (Gregory), 118
Oriskany ores, 531
Oroche Peak, 371
Orthoclase, 447
Ortiz laccolith, New Mexico, 369; section of, 369
Orton, E., on accumulation of oil, 513
Oruro tin field, 342
Ottrelite, 122, 129
Oxidation of sulphides (Buehler and Gottschalk), 782
Ozokerite, marine origin of, 618
Ozokerite veins, 113

Paigeite, 217
Paleozoic area of Georgia, geology of, 47
Paleozoic intrusives, epoch of, 412
Palliser area, coal, 5, 8
Paragenesis, of copper ore, Alaska, 209
Parisian, Eocene, 91
Park, J., on propylite, 636
Parkham on selenium, 552

Paskapoo formation, 2
Paul and Tietze, on geologic structure of central Galicia, 111
Pay streaks, in oil wells, 146, 509
Pazna tin district, 351
Pebble-reef, origin of, 118, 125
Peckham, on the derivation of oils, 612; on petroleum, 622; on Trinidad asphalt, 609
Pegmatite dikes, 737
Penfield and Ford, on calaverite, 545
Pennsylvania, magnetite deposits, 385
Peridotite, 131; from De Beers mine, micro-drawing of, 439; character of, 442–449
Peridotite, diamond-bearing, of Kimberley, South Africa, Petrographic note on the (Hartog), 438
Perofskite, 448
Petite Anse Island, model of, 27
Petrographic note on the diamond-bearing peridotite of Kimberley, South Africa (Hartog), 438
Petrography, of Bolivia tin deposits, 335; of Brewster district, N. Y., 716; of Hauraki gold field, 632; of peridotite from De Beers mine, 443
Petroleum, derivation from land-plants, arguments against, 611; formation from organic matter, 625; in Pennsylvania, 566; mode of accumulation of organic material to produce, 619; optical properties of, 627; vegetable origin of, 616, 621 (*see also* Oil)
Petroleum, On the origin of (Dalton), 603
Petrology, elements of, 62
Petzite, 555, 557
Phase of ground water problems in the West (Mendenhall), 35
Phenocrysts, 444
Phenomena, Some, of the folding of rock strata (Nason), 421
Philippine coalfields, geology of, 228
Philippine Islands, The coal resources of the (Smith), 224
Phillips, on natural gas, 607, 616
Phlogopite, 444, 446
Phosphorus, in Georgia ores, 51
Pipes, of South African diamond mines, 439
Pirsson, L. V., review of work by, 62
Pitch, defined, 58
Pitch length, defined, 58
Pitman, E., on a tin-bearing dike, 325
Placer theory of origin of Rand gold deposits, 120, 480; objections to, 123
Pliocene, Baku region, 91; Louisiana, 18; Rumania, 102
Plunge, defined, 59
Pockets of ore, 53
Polillo coal field, Philippine Islands, 232
Pontian, Pliocene, 102
Port Clarence limestone, Alaska, 216
Post-Pliocene epoch, of ore-deposition, 418
Potok oil-field, 114
Potonié, on the original materials of petroleum, 611
Pratt, J. H., on asbestos veins, 136
Pre-Cambrian deposits, distribution of, 411; characteristic metals of, 411
Pre-Cambrian period, of ore deposition, 411, 414
Precipitation, by Weber shales, 316; from salt solutions, conditions for, 23
Pressure, of oil and gas, 515, 527
Pretoria beds, 120
Problems in the geology of the Hauraki gold fields, New Zealand (Finlayson), 632
Propylite, 633, 635
Psilomelane, 49
Pumpelly, on changes in copper-bearing rocks, 159
Putnam, B. T., analysis by, 741, 745
Pyrite, 129, 209, 376; experiments upon, 784; in placer sands, 378; in the Rand, 122, 477; weathering of, 377
Pyrolusite, 49
Pyroxene, 446
Pyroxenite, 131
Pyrrhotite, 209

Quartz, 211, 447, 690
Quartz porphyry, 327, 336, 362
Quartz tourmaline, 363
Quartzite schist, 336
Quaternary, Baku region, 90; Louisiana, 18
Quebec, On the asbestos deposits of the eastern townships of (Dresser), 130
Quebec, southern, geology of, 130

Radziszewski, on the formation of petroleum by the action of bacteria, 623

Rakusin, on optical phenomena of petroleum, 608, 626
Rand banket, features of, 373
Rand gold district, section of, 471
Rand goldfield, The origin of the gold of (Gregory), 118
Ransome, F. L., reviews by, 62, 391, 490
Ransome, F. L., and Calkins, F. C., review of paper by, 178
Recent literature on economic geology (Loughlin and Clapp), 76; (Loughlin and Allan) 188, 283, 397, 580, 792
Redwood, on petroleum, 610
Reid, on replacement of pyrite, 211
Reinbolt, O. H., on coal in the Philippines, 226
Renault, on the origin of petroleum, 616
Residual decay, 51
Reviews—
Coals of South Wales, with special reference to the origin and distribution of anthracite (Strahan and Pollard) White, 274
Economic geology of the Georgetown quadrangle, Colorado (Spurr and Garrey) Crosby, 493
Elements of optical mineralogy (Winchell and Winchell), Calkins, 671
Florida State Geological Survey, First annual report (Sellards), Bain, 186
Fluorspar deposits of Kentucky (Fohs), Burchard, 571
Geology and ore deposits of the Cœur d'Alene district, Idaho (Ransome and Calkins), Buckley, 178
Geology of the gold fields of British Guiana (Harrison), Ransome, 490
Gold, its geological occurrence and geographical distribution (Maclaren), Ransome, 391
Graphite, its properties, occurrence, refining and uses (Cirkel), Hess, 661
Handbook for field geologists (Hayes), Lawson, 667
History of the clay-working industry in the United States (Ries and Leighton) Hice, 667
Iron ores of the Clinton formation of New York (Newland and Hartnagel), Holden, 281
Iron ores of the Iron Springs District in southern Utah (Leith and Harder), Kemp, 790
Magnetite and zinc ores of Franklin Furnace quadrangle (Spencer), Leith, 265
Magnetite ores of Passaic quadrangle (Hibernia Mine) (Bayley), Leith, 265
Magnetite deposits of the Cornwall type in Pennsylvania (Spencer), Leith, 385
Mineral resources of Virginia (Watson), Steidtmann, 386
Ore deposits of South Africa. Part I, Base Metals (Johnson), Hess, 577
Report on the examination of some iron ore deposits in the districts of Thunder Bay and Rainy River, Province of Ontario (Hille), Steidtmann, 575
Rocks and rock minerals, a manual of the elements of petrology without the use of the microscope (Pirsson), Ransome, 62
Second report on the clay deposits of Georgia (Veatch), Lines, 573
Sketch of the mineral resources of India (Holland), Butler, 270
Study of ore deposits for the practical miner (Wallace), Kemp, 273
Treatise on gold and silver (Crane), Emmons, 67
Untersuchung und Bewertung von Erzlagerstätten (Krusch), Lindgren, 65
West Virginia Geological Survey. Vol. II(A) Supplementary coal report (White), Campbell, 71
Rhang-el-Melah, Algeria, salt deposits, 31
Rhyolite, 687, 692; analyses of, 690, 693
Rhyolite-dacite, 698
Rhyolite dike, Tonopah, 690
Rhyolite porphyry, 301, 305
Riabinin, A., on oil-fields of Signakh district, 90; on the Binagadi oilfield, 97
Richards, Mrs. E. H., on agalmatolite, 244; on ankerite, 244
Rickardite, 546
Ries, H., and Leighton, H., review of work by, 667

Rivière, on the origin of bitumen, 604
Rock decay, in Georgia, 54
Rock-flowage, zone of, 367
Rock movement, 429
Rock salt, The geological occurrence of, in Louisiana and east Texas (Harris), 12
Rock strata, Some phenomena of the folding of (Nason), 421
Rocks, of Tonopah mining district, 687
Rope, on the formation of coal, 613
Ropianka beds, Cretaceous, 110
Rose, G., on pyrite in placer sands, 379
Rumania, physiographic zones of, 101
Rumanian oil, origin of, 103
Rumanian oil-fields, 99; difficulties in, 107
Rumbold, W. R., *The origin of the Bolivian tin deposits*, 321–364
Ruttman, F. S., on Brewster iron ore, 742

Sabatier and Senderens, on the origin of hydrocarbons, 606
Sabine stage, 15
Sadtler, on the origin of petroleum, 610
Saline deposits, 12
Saline solutions, movement of, 25; origin of, 28
Salt, precipitation of, 23
Salt deposits, of New York-Ontario area, origin, 33
Salt Islands, Louisiana, 12
Salt region of lower Mississippi, stratigraphy of, 13
Salt water, in oil-bearing beds, 529; in oil pools, 154; in oil wells, 146
San Bernardino Valley, irrigation in, 36
San Pedro copper deposits, New Mexico, 366, 367
San Roque tin mine, 334
Santa Ana River, utilization of, 36
Sapropel, 621
Sarmatian, Miocene, 91, 102
Sarmatian sandstone, Miocene, 109
Sawatch range, uplift of, 307
Schist, microscopic section of, 731
Schodnica-Boryslaw oil-field, section of, 112, 113
Schodnica-Urycz oil-field, 112
Scientific notes and news, 84, 195, 290, 407, 499, 593, 676, 801
Section of, Big Bonanza mine, Alaska, 205. Concordia tin lode, 330; Elisa tin lode; Galicia, central, 111; Hundred-foot sand, Sewickley, Pa., 145; Jiminez, Mex., garnetized contact zone, 371; Krosno oil-field, 114; Maros Valley, Hungary, 29; Mizpah and Silver Top shafts, Tonopah mining district, 684, 686; Moldavia, Trotus Valley, 104; Montana Tonopah shaft, 685; Negro Pabellon tin district, 347; oil-bearing beds, 527; Ortiz laccolith, N. Mex., 369; Prahova region, Rumania, 106; Rand gold district, 471; Rhang-el-Melah, Algeria, 32; Schodnica-Boryslaw oil-field, 112, 113; Sierra Madre Oriental, Nuevo Leon, Mex., 424, 426; Sloboda-Rungurska oil-field, 111; Tarnawa-Wielpole-Zagorz oil-field, 114; Tonopah district, 705; Tuertos laccolith, N. Mex., 371
Sedimentary gneissic rocks, 718
Sedimentary iron ores, epochs of, 412
Segregated veins, 755
Selective deposition, of minerals, 423
Selenium, reactions, with gold, 551; with silver, 552
Sellards, E. H., review of report by, 186
Sendersens, on selenium, 552
Sequence of ore-deposition, at Aspen, Colo., 318
Serpentine rocks, 130
Sewickley quadrangle, Pa., oil pools in, 141
Shaler, N. S., on Brewster iron ore, 742, 747
Siderite, 244, 448
Siebert tuff-beds, 704
Sierra Madre Oriental, Nuevo Leon, Mexico, geological section of, 424, 426
Silver, reactions with tellurium, 552
Silver fault, Aspen, Colo., 310
Simpson, G., on coal at Edmonton, 1
Singewald, J. T., Jr., *The iron ores of Maryland*, 530–543
Sjögren, on Palæogene deposits of Baku, 92
Sketch of the geology of the Baku and European oil-fields (Dalton), 89
Sloboda-Rungurska oil-field, 111
Smith, P. S., on pyrite in sand, 378
Smith, W. D., *The coal resources of the Philippine Islands*, 224–238

Smuggler mine, geologic history of, 311; mineralization of, 313
Smyth, H. L., and Smith, P. S., on Ely copper ores, 769
Sokolov, on the composition of bitumens, 610; on the origin of bitumens, 606
Sollas, on rocks of Hauraki gold fields, 635
Solontu oil field, 105
Solutions, selenium and gold, 551; tellurium and gold, 550; tellurium and silver, 551
Some features of the Alaskan tin deposits (Knopf), 214
Some observations on the tellurides (Lenher), 544
Some phenomena of the folding of rock strata (Nason), 421
Some regionally metamorphosed ore deposits and so-called segregated veins (Emmons), 755
South Africa, diamond fields of, A bibliography of (Julien), 453
South Africa, ore deposits of, 577
Southern California, valley of, 37; ground water of, 38
Specular hematite, Piedmont region of Maryland, 540; analyses of, 540
Spencer, A. C., review of papers by, 265, 385
Sphalerite, 211, 244; experiments upon, 784
Spindle Top dome, 28
Spouters, in Baku oil fields, cause of, 96
Spurr, J. E., *Ore-deposition at Aspen, Colorado*, 301–320; on metasomatic alterations, 222; on ore-deposition, 249, 303, 318, 658; on siderite, 634; on succession of copper minerals, 211; on the geology of the Tonopah mining district, 681
Spurr, J. E., and Garrey, G. H., review of paper by, 493
Stability, of metals, 432
Stannite, 219, 221
Static friction, 151
Stefanescu, S., on Tertiary formations of Rumania, 102
Steidtmann, E., reviews by, 386, 575
Stelzner, A. W., on Bolivian tin deposits, 321
Stewart, on Rumanian oil-fields, 107
Stewart, C. A., discussion by, 485
Stone cabin fault, Tonopah, 710
Stope length, defined, 58
Strahan, A., and Pollard, W., review of paper by, 274
Strata, rock, Some phenomena of the folding of (Nason), 421
Stratigraphy, of salt region of Lower Mississippi, 13
Structure, of Baku oil region, 95; of crystalline area of Georgia, 47; of Galician oil-fields, 111; of Lower Mississippi region, 19
Studies in the application of the anticlinal theory of oil and gas accumulation (Munn), 141
Stutzite, 546
Sulphides, Oxidation of (Buehler and Gottschalk), 782
Sulphur, occurrence in domes, 25
Sumgait series, 92
Syenite, microscopic section of, 725
Syenitic gneiss, 724
Sylvanite, 545, 549
Szagnocha, L. W., on oil in east Galicia, 111

Table of formations, of Louisiana, 13; of Lower Mississippi region, 13
Tarnawa-Wielpole-Zagorz oil-field, section of, 114
Tars, composition of, 610
Teisseyre, L., on geology of Bacauan Carpathians, 104
Telluride of gold, artificial, 558
Tellurides, Some observations on the (Lenher), 544; behavior to heat, 556
Tellurite, 546
Tellurium, association with gold, 547; history of, 544; occurrence of, 545; reactions, with gold, 550; with silver, 551; transportation by natural solutions, 561
Tertiary, of Baku oil regions, 90; of Galicia, 109; of Louisiana, 14
Tertiary epochs of ore deposition, 416, 417
Terrestrial magnetism, abnormalities of, in Louisiana, 20
Tetradymite, 546
Tetrahedrite, 240
Texas, east, rock salt in, 12
Theories, The anticlinal and hydraulic, of oil and gas accumulation (Munn), 509
Thermal waters, Anse La Butte, 27
Thetford district, asbestos deposits of, 138
Tibbals, C. A., Jr., experiments with tellurides, 553, 560
Tin, of Bolivia, character and origin, 357

Tin deposits, Alaska, geographic distribution of, 214; geology of 216; Bolivia, location of, 322; map of, 323
Tin deposits, Alaskan, Some features of the (Knopf), 214
Tin deposits, Bolivian, origin of (Rumbold), 321
Tin industry, of Bolivia, 358
Tisesti sandstone, 105
Titanium, in magnetite ore, 543
Tonopah mining district, The geology of the producing part of (Burgess), 681
Tonopah mining district, 681; geologic map of, 683; sections in, 684–686, 705; views of, 706–708; geologic history of, 711; geologic column of, 711
Tonopah rhyolite-dacite, 704
Topalpite, 546
Tortonian, Miocene, 91, 102
Tourmaline, 215, 218, 333
Transportation by gravity, of oil, 518
Transvaal, geological map, 471
Tres Cruces district, microscopical character of the rocks of, 335
Tres Cruces tin field, 322; geology of, 322
Triassic traps, epochs of, 413
Tuertos group, New Mexico, 368
Tuertos laccolith, New Mexico, 371; section of, 371
Tuff, indurated stratified, 688

Uhlig, V., on geology of Galicia, 109

Vaal River beds, 120
Vadose shoots, 57
Valencianite, 634; analysis of, 634
Valley of southern California, 37; ground water of, 38
Van Hise, C. R., on contact deposits, 367; on metamorphism, 277; on transportation of gold, 561
Veatch, A. C., on salines, 15
Veatch, O., review of report by, 573
Vein system, Tonopah mining district, 702
Veins, asbestos, character of, 133
Ventersdorp beds, 120
Vicksburg beds, 20
Vicksburg stage, 16
Ville, on "dunes," 33
Virginia, mineral resources of, 386
Vogt, on denudation, 367
Voit, F. W., on the origin of the Rand gold, 119
Volcanic rocks, Bolivia, 323

Wadsworth, M. E., on pyritic ores in Newfoundland, 771; on wollastonite, 243
Waihi gold deposits, 642
Wales, coals of, 274
Wall, on oil from lignite, 609
Wallace, J. P., review of work by, 273
Walter, B., on oil production in Bukovina, 108
Warren and Storer, on hydrocarbons, 613
Water, at great depths, 521; downward circulation of, 171; in the arid West, 35 (*see also* Mine waters)
Water, ground, problems in the West, A phase of (Mendenhall), 35
Water conditions, in oil and gas bearing beds, 532
Water plane fluctuations, in southern California, measurement of, 44
Waterberg sandstones, 120
Watson, T. L., *The manganese ore-deposits of Georgia*, 46–55; review of work by, 386; on copper ores of Seminole, Ga., 774
Weathering of rocks, Hauraki gold fields, 636
Weber formation, Colorado, 304
Weed, W. H., on Ducktown ores, 775; on enrichment of mineral veins, 304, 314; on Jiminez copper deposits, 372; on ore deposition, 249; on segregation copper deposits, 758. on the Virgilina district, 772
Wehrlite, 546
Weigel, on solubility of sulphides, 779
Weisner quartzite, 51
Wendt, A. F., analyses by, 741, 745; on Brewster iron ore, 742; on Gardner Mountain ores, 757
Werner, A., on inorganic chemistry, 548
West Virginia, coal report, 71; coal reserves, 262
White, D., on the origin of coal, 653; review by, 274
White, I. C., review of work by, 71
Whitney, J. D., on segregated veins, 757
Wietze-Steinforde oil-field, 117
Williams, G. F., on diamonds, 452
Wilson, F. B., analyses by, 161, 165
Winchell, A. N., on the oxidation of pyrite, 782
Winchell, N. H., and Winchell, A. N., review of work by, 671

Windaus, on cholesterol, 628
Witt, O. N., on the origin of petroleum, 617
Witwatersrand formation, 471
Witwatersrand system, 119
Wolfram, 349
Wollastonite, 243, 247

Young, G. J., analysis by, 690
Yung and McCaffery, on the San Pedro mines, 367, 370

Yuschkin, E., on the Khirdirzindi oil-field, 90

Zeolites, 447
Zies and Gill, analyses of iron ores, 532–543
Zinc, in Central States, 175
Zinc and lead concentration, epochs of, 413
Zinc and lead deposits, origin, 413
Zinc ores, New Jersey, 265
Zwitter, 216